



**ADDIS ABABA UNIVERISTY  
SCHOOL OF GRADUATE STUDIES  
COLLEGE OF NATURAL SCIENCES  
DEPARTMENT OF COMPUTER SCIENCE**

**Cluster Based QoS Aware Routing in MANET**

**Kebebew Ababu Yitayih**

**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS  
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**Kebebew Ababu Yitayih**

**Advisor: Mulugeta Libsie (PhD)**

APPROVED BY EXAMINING BOARD:

<u>Name</u>	<u>Signature</u>
1. Dr. Mulugeta Libsie, Advisor	_____
2. _____	_____
3. _____	_____

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**Dedicated to:**  
My mother

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## Table of Contents

List of Figures.....	iii
List of Algorithms.....	iv
List of Tables.....	v
Acronyms.....	vi
Chapter One: Introduction.....	1
1.1 Background.....	1
1.2 Statement of the Problem.....	2
1.3 Objectives.....	3
1.4 Scope and Limitations of the Study.....	4
1.5 Methods.....	4
1.6 Significances of the Study.....	5
1.7 Thesis Organization.....	5
Chapter Two: Literature Review.....	6
2.1 Overview.....	6
2.2 Characteristics of MANETs.....	7
2.3 MANETs Technology.....	8
2.4 Routing and Routing Protocols in MANETs.....	9
2.4.1 Proactive Routing Protocols.....	9
2.4.2 Reactive Routing Protocols.....	20
2.4.3 Hybrid Routing Protocols.....	23
2.5 Comparison on the Properties of MANETs Routing Protocols.....	24
2.6 QoS and QoS Routing in MANETs.....	26
2.6.1 Quality of Service (QoS) in MANETs.....	26
2.6.2 QoS Routing in MANETs.....	27
Chapter Three: Related Work.....	29
3.1 QoS Routing Using Proactive Routing Protocols.....	29
3.2 QoS routing using Reactive Routing Protocol.....	35
3.2.1 QoS routing using AODV Routing Protocol.....	35
3.2.2 QoS routing using DSR Routing Protocol.....	36
3.2.3 QoS routing using DYMO Routing Protocol.....	37
3.3 QoS Routing using Hybrid Routing Protocols.....	38
3.4 Comparison of Routing Protocols in MANETs.....	38
3.5 Summary.....	40
Chapter Four: Design of the Proposed Solution.....	42
4.1 Overview.....	42
4.2 Architectures of the Proposed Solution.....	42
4.2.1 Clustering.....	45
4.2.2 OLSR Protocol.....	49
4.3 Other Modules.....	58

4.4 Summary.....	59
Chapter Five: Prototype Implementation and Evaluation .....	60
5.1 Overview.....	60
5.2 Development and Simulation Tools .....	60
5.3 Prototype Implementation.....	62
5.4 Analysis of MPR Selection Algorithms .....	67
5.4.1 Description of MPR Selection Algorithms .....	67
5.4.2 Costs of MPR Selection Algorithms.....	69
5.4.3 Simulation Results of MPR Selection .....	71
5.5 Simulation Experiments and Results.....	73
5.5.1 Simulation setup .....	73
5.5.2 Performance Evaluation Metrics and Results .....	74
5.6 Summary.....	79
Chapter Six: Conclusion and Future Work .....	80
6.1 Conclusion .....	80
6.2 Future Work.....	81
References .....	83
Appendix A: NED file Code for the Proposed QoS Routing .....	88
Appendix B: Ad hoc host Simulation Parameters .....	90

## List of Figures

Figure 2.1: Sample Wireless Ad hoc Network .....	6
Figure 2.2: Data Flow in OLSR Protocol.....	13
Figure 2.3: OLSR packet Format.....	16
Figure 2.4: Sample Video Streaming .....	28
Figure 4.1: Proposed Architecture in MANET Layer.....	43
Figure 4.2: Proposed QoS Routing Model .....	49
Figure 4.3: MANET Nodes .....	53
Figure 5.1: MANET Setup .....	62
Figure 5.2: Connection of Modules in one MANET Host .....	63
Figure 5.3: Sample Routing Table Snapshot.....	66
Figure 5.4: Sample Video Streaming Snapshot.....	67
Figure 5.5:EED Result Recorded by all Nodes .....	76
Figure 5.6: EED Result Recorded by one Node .....	76
Figure 5.7: AEED for Routing a Packet on different QoS Routing Schemes .....	75
Figure 5.8: PDR Result for Routing a Packet on different QoS Routing Schemes .....	76
Figure 5.9: NRL Result for Routing a Packet on different QoS Routing Schemes.....	77
Figure 5.10: Throughput Result for Routing a Packet on different QoS Routing Schemes .....	78

## List of Algorithms

Algorithm 4.1: Modified Lin's Clustering Algorithm .....	48
Algorithm 4.2: Algorithm for MPR Selection.....	52
Algorithm 4.3: Algorithm for Rout Computation.....	56
Algorithm 4.4: Algorithm for Forwarding Packets.....	58

## List of Tables

Table 2.1: Properties of MANETs Routing Protocols .....	24
Table 3.1: Comparison of QoS Routing Protocol.....	39
Table 4.1: MPR Node Selection .....	53
Table 5.1: Set of MPRs and MPR Selector .....	65
Table 5.2: Summary of MPR Selection Algorithms .....	68
Table 5.3: Cost Comparison Result of MPR Selection Algorithms .....	70
Table 5.4: MPR Selection Performance Result .....	72
Table 5.5: Summary of Simulation Parameters .....	74
Table 5.6: Performance Evaluation Result .....	75

## **Acronyms**

AODV: Ad hoc Distance Vector

DSDV: Destination Sequenced Distance Vector

DSR: Dynamic Source Routing

DYMO: Dynamic MANET On demand

FSR: Fisheye State Routing

IEEE: Institute of Electrical Electronics Engineering

IETF: Internet engineering Task Force

IP: Internet Protocol

MANETs: Mobile Ad hoc Networks

MPR: Multi Point Relay

OLSR: Optimized Link State Routing

OMNET++: Objective Modular Network Test-bed in C++

QoS: Quality of Service

RFC: Request for Comments

TC: Topology Control Message

TCP: Transmission Control Protocol

UDP: User Datagram Protocol

VoIP: Voice over Internet Protocol

ZRP: Zone Routing Protocols

## Abstract

Millions of people nowadays have portable computers like mobile phones and pocket PCs, and they generally want to stream videos, communicate over VoIP, attend online conferences, and read their e-mail wherever in the world they may be. Hence, creating dynamic communication infrastructures between mobile devices is becoming a very big issue for many researches. Ad hoc networks allow mobile devices to interconnect in areas with no pre-existing communication infrastructure. However, in this network various QoS parameters like delay, overhead, throughput, packet loss, etc, must be predefined to satisfy QoS requiring applications such as multimedia communication, online game, etc. Thus a QoS supporting routing protocol that finds the optimal routing path between two or more mobile devices is needed to be developed. In this thesis, based on reviewed surveys, proactive protocols, particularly OLSR, is selected for QoS routing. The protocol has lower latency and overhead because each node selects a set of MPR nodes from its neighbors to forward broadcasting messages during flooding. However, selecting suitable MPRs by considering different QoS metrics is a key point in OLSR.

This work proposed cluster topology and deploy an OLSR protocol for optimal route computation of a network. Based on multiple QoS metrics, algorithms for grouping MANET nodes, selecting MPR nodes, maintaining optimal routing information, and forwarding of packets are designed to improve the services of the protocol. Three QoS support MPR selection approaches are assessed and compared with our proposed QoS MPR selection. The result shows that the proposed QoS metric that considers node connectivity, delay, quality, and bandwidth QoS constraints for MPR selection provides better performance in terms of network overhead, stability, and number of MPRs. In order to reduce the routing complexity, overhead of broadcasting messages, delay, and packet loss of a network, we have assessed and modified a lower maintenance clustering algorithm.

We have evaluated the performance of our proposed QoS aware routing through MANET simulation environment. Within 50 MANET nodes, simulation experiment shows that the proposed QoS routing results is 28.94 ms average end to end delay, 74% packet delivery ratio, 1.92 routing load, and 654.93 Byte/Sec throughput, whereas QoS MPR-1 results is 41.09 ms average end to end delay, 58% packet delivery ratio, 2.81 routing load, and 592.10 Byte/Sec throughput, and finally, QoS MPR-3 results is 33.50 ms average end to end delay, 62% packet delivery ratio, 3.05 routing load, and 638.47 Byte/Sec throughput. Thus, considering multiple QoS metrics for MPR selection and deploying the routing protocols on clustered topology of a mobile ad hoc network provides better performance and improves the services of mobile nodes.

**Keywords:** *MANET, OLSR, MPR, Clustering in MANETs, QoS Routing, QoS, Multimedia*

# Chapter One: Introduction

## 1.1 Background

Computing is an evolutionary process with each generation improving on the previous one's technology, architecture, software and applications. In recent years, with the advent of new technologies and the demand for flexibility and ease in working environment, the use of mobile computing has enjoyed a tremendous rise in popularity. Devices can be able to work everywhere at any time without the need of having a fixed infrastructure. Nowadays there are more than billions of wireless devices in use for the purpose of different applications. However, creating a connection and making message exchanging between mobile nodes is a big issue in such kind of technologies.

Therefore, Mobile Ad Hoc Networks (MANET) [1, 12] is a dynamic multi-hop wireless ad-hoc communication network that allows people and devices to seamlessly interconnect in areas with no pre-existing communication infrastructure or central administration. However, the biggest challenge in this kind of networks is to find a path between the communication end points, which is aggravated through node mobility. Thus, a routing protocol will play a major role in an ad hoc network to connect nodes that cannot communicate with each other directly and does not stop to be a subject of research work to improve the performance of wireless networking solutions.

For our work, considering its futures of maintaining routing information, we have chosen Optimized Link State Routing (OLSR) [1, 4, 5, 6] which is a type of proactive link state protocol and uses Hello and Topology Control (TC) messages to discover and then disseminate link state information throughout the mobile ad hoc network. Individual nodes use this topology information to compute next hop destinations for all nodes in the network using shortest hop forwarding paths. OLSR is best method [6, 8, 9, 11] with emphasis on reducing the overhead because each node selects a set of Multipoint Relays (MPR) from its neighbors to forward broadcast messages during the flooding process, and at the same time, provides a minimum hop route. The protocol has lower latency since routes are maintained at all times. It is also the best choice for a network having higher node mobility. MPR selection is the key point in OLSR. Therefore, in this protocol designing a new efficient MPR selection approach is found as the best alternative to drive better QoS routing.

In this thesis, to provide efficient QoS routing in MANETs using OLSR protocol, a new QoS support routing approaches will be designed. The approaches will be deployed on a clustered MANET topology, and a new heuristic algorithm will select MPR nodes appropriately, compute the routing table effectively, and forward a packet efficiently with aware of multiple QoS constraints. The algorithm is adaptive in nature and it can take quick reaction for network restructure and node failure. It selects a MPR node based on a latest modified version of the OLSR routing protocol by considering constraints like node connectivity, quality, bandwidth, and delay of neighbor nodes status with minimum number of overlapping. Furthermore, to maintain routing information, multiple constraints like hop count, bandwidth, next good routing paths and others to find best routing path from source to any destination node will be considered. Therefore, at the end of this work, a better QoS routing will be derived by alleviating QoS routing problems like end to end delay, throughput optimization, transmission errors and network load on the aspects of network scalability, node density, etc, within the algorithm.

## **1.2 Statement of the Problem**

It is well known that existing protocols for mobile ad hoc networks (MANETs) have certain weaknesses like delay, overhead, packet lose, etc. [10, 13]. In MANETs, routing and guaranteeing quality of service (QoS) is much more challenging than in wired networks, mainly due to node mobility, multi-hop communications, unpredictable link properties, resource constraints, contention for channel access, and a lack of central coordination. Also, in MANETs equipping devices to continuously maintain the information required to properly route traffic is more challenging than wired networks. QoS guarantees are required by most multimedia and other time sensitive applications. The difficulties in the provision of such guarantees have limited the usefulness of MANETs.

MPR selection approaches which are done so far are not effective enough because the node selects the neighbor that covers the most unreachable 2-hop neighbors as MPR [6, 35]. This strategy limits the number of MPRs in the network, ensures that the overhead is as low as possible. However, in QoS routing, by such an MPR selection mechanism, the good quality paths may be hidden to other nodes in the network. And this will leads to delaying of transmissions for a time sensitive applications. The aim of the MPRs during the broadcast phase is to forward packets effectively by reducing redundancy in order to limit the traffic and risk of collisions. However, in the existing works resource utilization and overlapping of nodes at time of MPR

node selection as well as maintaining of routing information were not considered. They are mainly focused on minimizing the size of MPRs set. Thus, a new heuristic based is required for selecting MPRs with minimum overlapping for minimizing the possibility of useless retransmissions and receptions and reduced loss of packets.

However, in the last decade, much research attention has focused on providing QoS assurances in MANET protocols. None of them are adequate enough that considered multiple appropriate QoS criteria to select MPR nodes, most of them only answer part of the questions by considering one or two QoS parameters. Because of the rising popularity of multimedia applications and potential commercial usage of MANETs, a new routing approach is required to provide an efficient QoS routing by maintaining efficient optimal routing information. In MANET, even if it enhances the performance of QoS routing, combining multiple criteria in the routing process is a tedious task. In this thesis, we will design a new heuristic algorithm that enhances the existing protocols to satisfy better for QoS requiring applications such as voice/video conferencing, VoIP, and other time sensitive applications. To minimize consumption of network resources, to manage the routing information easily, the approaches will be deployed on grouped MANET nodes. The new MPR selection algorithm promises to resolve the problems of the existing routing protocols by considering multiple constraints like node connectivity, bandwidth, quality, and delay with minimum overlapping of nodes.

### **1.3 Objectives**

#### **General Objective**

The general objective of this thesis is to propose cluster based QoS aware routing strategies for mobile ad hoc networks.

#### **Specific Objectives**

In order to achieve the general objective, the following specific objectives are set.

- Identify and investigate the current protocols of routing in MANETs.
- Assessing the difficulties faced by routing in MANET protocols.
- Identification of appropriate QoS matrices to improve the existing protocols.
- Design an algorithm for MPR node selection that satisfies better QoS routing by considering appropriate QoS matrices constraints in time sensitive applications.

- Select an efficient clustering scheme for organizing and managing of MANET nodes.
- Design an appropriate mechanism for optimal route calculation.
- Implement a QoS aware routing approaches under a MANET simulation environment.
- Testing and evaluating the performance of the new algorithms through simulations to show that these QoS support routing algorithm do improve MANET services.

#### **1.4 Scope and Limitations of the Study**

The scope of this thesis is limited to designing and implementing clustered based QoS aware routing in MANETs using OLSR protocols. Different algorithms for grouping MANET nodes, selecting MPR nodes, maintaining optimal routing information, and forwarding of packets effectively are designed. The approaches will improve the performance of the existing routing protocols with in MANETs by satisfying better QoS routing. The study will take attention on providing lower end to end packet delivery for application that needs QoS routing by addressing issues like delay, overhead, throughput, transmission error, etc.

Our proposed work will not cover the following tasks:

- Security of the channel to protect against attack.
- Load balancing in case of high traffic flow.

#### **1.5 Methods**

##### **Literature Review**

In order to achieve the objectives of this thesis various resources like books, research papers and other documents will be used for the purpose of understanding QoS routing in MANETs routing protocols in general and QoS routing using OLSR protocol in particular. Techniques and approaches appropriate for development of a routing algorithm using OLSR protocol will also be reviewed. Moreover, suitable cost matrices for the selection of MPR node and grouping of nodes, and methods to support end to end connection will also be explored.

##### **Design and Implementation**

In the design phase, proposed models and algorithms which are specified in the objective of this

paper will be design. Due to high cost of MANET nodes, we will implement the proposed QoS routing using a simulated MANET environment.

### **Evaluation of the Proposed Work**

Experiment will be conducted to test the effectiveness of our proposed QoS routing strategies, and evaluated in terms of its objective and contributions in comparison to what is already done using MANET simulation environment. Evaluation is conducted by considering different QoS parameters.

### **1.6 Significances of the Study**

In recent times, with the raise of portable devices as well as progress in wireless communication, ad hoc networking is gaining importance with the increasing number of wide spread applications. Thus, the contribution of this work will facilitate the services of Mobile Ad-Hoc Networks (MANETs) applications in many important situations such as military, commercial, conferencing, education, emergency services, etc. Devices allow users to access and exchange information regardless of their geographic position or proximity to infrastructure. In contrast to the infrastructure networks, all nodes in MANETs are mobile and their connections are dynamic. The set of applications for MANETs is diverse, ranging from large-scale, mobile, highly dynamic networks, to small, static networks that are constrained by power sources.

As MANETs gain popularity, mechanisms that provide us getting quality of MANET services also need to be improved. However, currently, due to lacking of efficient routing protocol, they have certain limitations to fully utilize the potential benefit provided by MANETs. Therefore, this work will enhance the usefulness of MANETs by providing better QoS support routing technique.

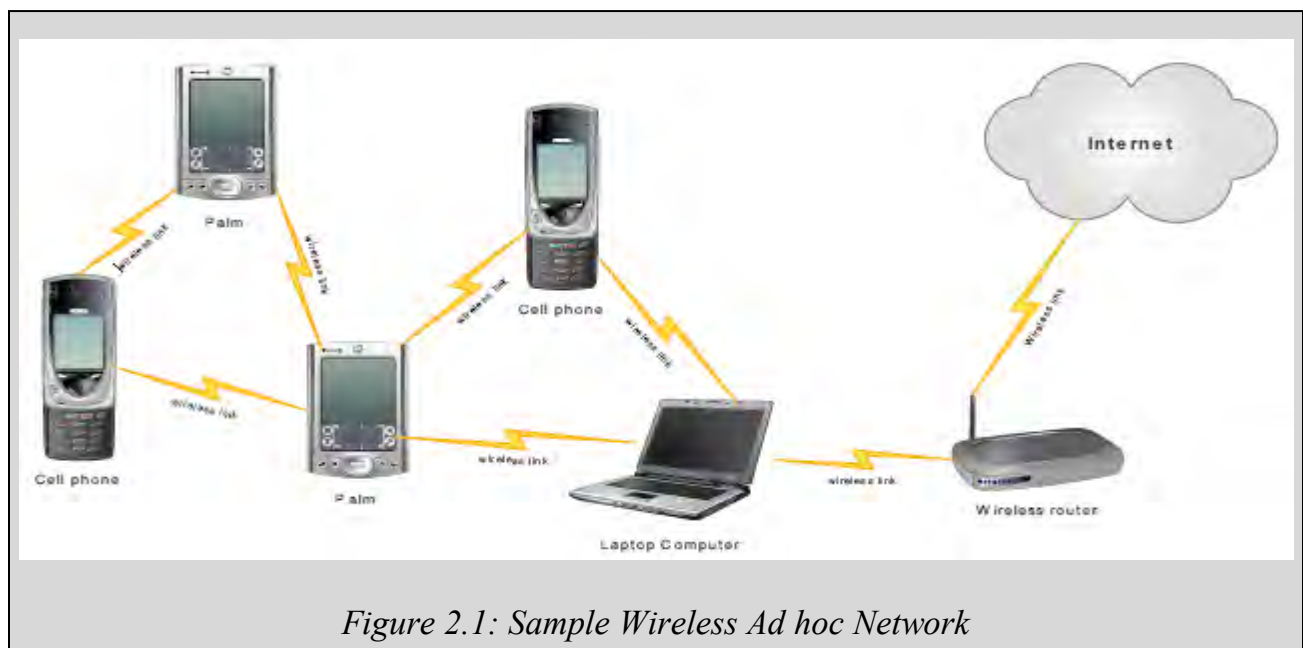
### **1.7 Thesis Organization**

The remaining Chapters are organized as follows. Chapter 2 presents a literature about MANETs and QoS routing in MANETs. Chapter 3 introduces related works which are conducted for routing a data on a MANET. Chapter 4 presents the detail of the proposed model and algorithms. Chapter 5 provides an extensive simulation study and evaluation of the proposed algorithms. Finally, the conclusions of the research and recommendations of future works are presented in Chapter 6.

## Chapter Two: Literature Review

### 2.1 Overview

A Mobile Ad-Hoc Network (MANET) [1, 2, 6, 10] is a dynamic multi-hop wireless network that is established by a group of mobile nodes on a shared wireless channel. As shown in Figure 2.1 [12], nodes may be computers or devices such as mobile phones and pocket PCs with wireless connectivity. The nodes communicate with each other and exchange network information, and network topology changes could occur randomly, rapidly, frequently and unpredictably. As a host, a node functions as a source and destination in the network and as a router, nodes act as intermediate bridges between the source and the destination giving store and forward services to all the neighboring nodes in the network. Easy deployments, speed of development, and decreased dependency on the infrastructure are the main reasons to use an ad hoc network. It allows people and devices to seamlessly internetwork in areas with no pre-existing communication infrastructure or central administration, have wide applications ranging from military operations, natural disaster, search and rescue operations and other applications such as meeting in a room, transport, etc. Each node is responsible for forwarding a packet it has received from one to another if required, until the packet reaches the destination.



MANET technology plays a fundamental role in a possible future of ubiquitous computing in which users are no longer aware of computation being done [15, 17]. Due to their ability of being intelligent, devices are self-organizing, packet forwarding, connecting to the Internet and they can be embedded pervasively to the physical world.

In MANETs, many research areas have potential study value and thus attract much attention. Currently, the popular research issues are routing, multicasting/broadcasting, location service, TCP and reliable transport, medium access control, radio interface, Quality of service, power management, and security. Finding efficient solutions to these fundamental issues could significantly increase the survivability of MANETs.

A MANET working group of the Internet Engineering Task Force (IETF) is currently proposing a number of research directions for improving the services provided by ad hoc networks [1, 12]. The group standardizes IP routing protocol functionalities which are suitable for wireless routing applications within both static and dynamic topologies with increase dynamics due to node mobility and other factors.

## 2.2 Characteristics of MANETs

According to the works in [1, 3, 8, 43] a MANET has the following features:

- **Autonomous Terminal:** In MANETs, each mobile terminal is an autonomous node, which may function as both a host and a router. In other words, besides the basic processing ability as a host, a mobile node can also perform switching functions as a router.
- **Distributed operation:** There is no central control of the network operations and so the control and management of the network is distributed among the terminals. The nodes involved in a MANET should collaborate amongst themselves and each node acts as a relay as needed, to implement functions, e.g., security and routing.
- **Multi-hop routing:** Basic types of ad hoc routing algorithms can be single-hop and multi-hop, based on different link layer attributes and routing protocols. Single-hop MANET is simpler than multi-hop in terms of structure and implementation, with the cost of lesser functionality and applicability. When delivering data packets from a source

to its destination out of the direct wireless transmission range, the packets should be forwarded via one or more intermediate nodes.

- **Dynamic network topology:** Since the nodes are mobile, the network topology may change rapidly and unpredictably and the connectivity among the terminals varies with time. A MANET should adapt to the traffic and propagation conditions as well as the mobility patterns of the mobile network nodes. The mobile nodes in the network dynamically establish connectivity among themselves as they move about, forming their own network on the fly. Moreover, a user in the MANET may not only operate within the ad hoc network, but may require access to a public fixed network (e.g., Internet).
- **Fluctuating link capacity:** The nature of high bit-error rates of wireless connection might be more profound in a MANET. One end-to-end path can be shared by several sessions. The channel over which the terminals communicate is subject to noise, fading, and interference, and has less bandwidth than a wired network. In some scenarios, the path between any pair of users can traverse multiple wireless links and the link themselves can be heterogeneous.
- **Light-weight terminals:** In most cases, the MANET nodes are mobile devices with less CPU processing capability, small memory size, and low power storage. Such devices need optimized algorithms and mechanisms that implement the computing and communicating functions.

### 2.3 MANETs Technology

Due to the innovation of portable devices and IEEE 802.11/Wi-Fi wireless protocol, ad-hoc network is becoming very popular [2, 3, 4, 12]. IEEE 802.11 is a set of media access control (MAC) and physical layer (PHY) specifications for implementing wireless local area network (WLAN) computer communication. Its fundamental task is to regulate the access of a number of nodes to a shared medium in such a way that certain application dependent performance requirements are satisfied. IEEE adopted the term ad hoc networks for the IEEE 802.11 Wireless LAN standards and IEEE 802.11 b, a, n, and g, etc. are the most widely used types of versions. In addition, today, Bluetooth and HiperLAN2 are among other alternatives that offer further technologies that can be used in ad hoc communications.

## **2.4 Routing and Routing Protocols in MANETs**

The absence of fixed infrastructure in a MANET poses several types of challenges [6, 9]. The biggest challenge among them is routing. Routing is the process of selecting paths in a network along which to send data packets. An ad hoc routing protocol is a convention, or standard, that controls how nodes decide which way to route packets towards its destination using most efficient path between computing devices in a mobile ad hoc network. Efficiency of the path is measured in various metrics like, number of hops, traffic load, transmission rate, bandwidth, etc.

In ad hoc networks, nodes do not start out familiar with the topology of their networks; instead, they have to discover it. The basic idea is that a new node may announce its presence and should listen for announcements broadcast by its neighbors. Each node learns about nearby nodes and how to reach them, and may announce that it can reach them too. The routing process usually directs forwarding on the basis of routing tables which maintain a record of the routes to various network destinations. Thus, constructing routing tables, which are held in the router's memory, is very important for efficient routing.

In MANETs to create a dynamic connection by alleviating routing problems like path breaks, topology changes, congestion and resource management, many routing protocols have been proposed over the last few years [1, 6, 10, 11]. These protocols can be broadly classified into three categories based on the way they find new routes or update existing ones and delivering of the message to the destination.

### **2.4.1 Proactive Routing Protocols**

Every proactive routing protocol usually needs to maintain accurate information in its routing table [10, 18]. It attempts to continuously evaluate all of the routes within a network. This means the protocol maintains fresh lists of destinations and their routes by periodically distributing routing tables throughout the network so that when a packet needs to be forwarded, a route is already known and can be used immediately. Once the routing tables are setup, then data (packets) transmissions will be as fast and easy as in the traditional wired networks.

Unfortunately, it is a big overhead to maintain routing tables in a mobile ad hoc network environment. Therefore, the proactive routing protocols have the following common disadvantages:

- Consume lots of network resources to maintain up to date status of network topology.
- Slow reaction on restructuring network and failures of individual nodes.

Therefore, proactive routing protocols are more appropriate for less number of nodes in networks which will need minimum delays of QoS required applications. These routing protocols are not suitable for larger networks, as they need to maintain node entries for each and every node in the routing table of every node. This causes more overhead and leads to consumption of more resources like bandwidth, processing power, etc. DSDV and OLSR are the most widely used proactive routing protocols which are discussed in the sequel.

#### **2.4.1.1 Optimized Link State Routing (OLSR)**

The Optimized Link State Routing Protocol (RFC 3626) is developed for mobile ad hoc networks [1, 6, 13, 25]. It is the most popular proactive link state protocol where nodes maintain the route information in a routing table, so a route is available immediately when it is required. The source node will be alerted by the topology control messages whenever the node mobility in the route or changes in the bandwidth happen. If there is any change in the topology, a new route will be recalculated.

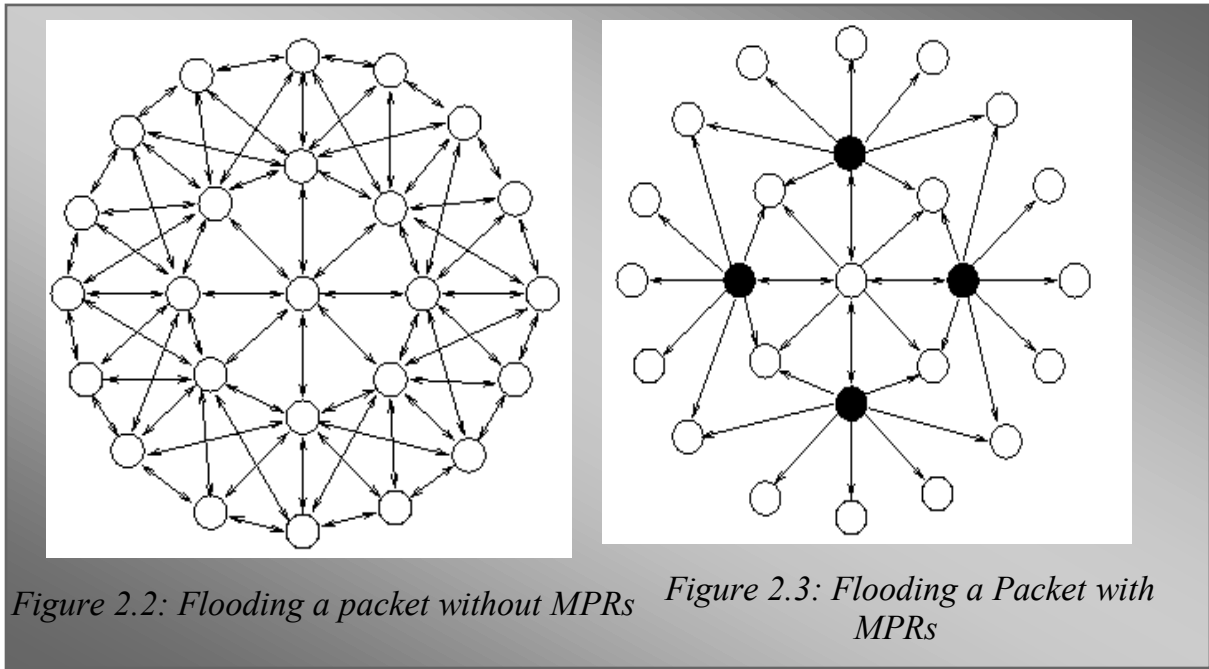
The key point why OLSR routing protocol differs from the other routing protocols is, instead of pure flooding, it uses Multipoint Relay (MPR) to reduce the number of hosts which broadcast the information throughout the network [13, 19]. The MPR is a node which is selected such that it covers all nodes that are two hops away. The nodes which are selected as a MPR by some neighbor nodes announce this information periodically in their control messages.

OLSRv2 is currently being developed within the IETF [1, 25]. It maintains many of the key features of the original including MPR selection and dissemination. Key differences are the flexibility and modular design using shared components: packet format, and neighborhood discovery protocol (NHDP). These components are being designed to be common among next generation IETF MANET protocols. It is standardized independently and applicable for other MANET protocols. Also in OLSRv2 the handling of multiple address and interface enabled nodes is different than OLSRv1. Four points need to be emphasized in OLSR.

- a. Neighbor sensing:** each node periodically broadcasts a HELLO message, containing the information about its neighbors and their link status. Each node must detect the neighbor

nodes with which it has a direct and bidirectional link. If a node finds its own address in a HELLO message, it considers the link to the sender node as bi-directional.

- b. Multipoint Relay Selection:** every node in the network selects its own set of MPRs. A set of selected one hop neighbor nodes are the MPRs. This covers all the two hop neighbors. MPRs minimize the flooding of the broadcast messages.



In Figure 2.2 [1, 12], each node broadcasts the incoming packet to all other neighbor nodes. This leads to a high number of unnecessary retransmissions resulting in high number of message overhead and losses of packets due to collisions of packets. But, in Figure 2.3 [1, 12], only black nodes which are selected as MPR will be in charge of forwarding the packets to the neighbor nodes. This will reduce the flooding of broadcast packets as well as the overhead of the networks.

- c. MPR Information Declaration:** a Transmission Control (TC) message is sent periodically by each node in the network to declare its MPR selector set, i.e., the message contains the list of neighbors who have selected the sender node as multi-point relay. The sequence number associated to this MPR selector is also attached to the list. Each node of the network maintains a topology table, in which it records the information about the topology of the network obtained from the TC messages.

- d. Routing Table Calculation:** to route the packets in the network each node maintains a routing table in the network. The route entries in the routing table consist of destination address, next-hop address, and estimated distance to destination. The routing table is based on the information contained in the neighbor table and the topology table. Therefore, if any of these tables is changed the routing table is recalculated to update the route information.

Surveys on the use of MANET routing protocol claim that OLSR has lower latency, better for high network mobility, provide optimal routes (in terms of number of hops), and good in scalability [2, 10, 11, 13]. Compared to the other types of routing protocols [4, 8, 11, 13], OLSR works best in large dense networks and it is a good candidate for QoS improvement. It is suitable for a network where frequent communication takes place in a collection of nodes rather than as a whole. In this protocol, each node has the knowledge as to for which node it acts as an MPR. The node *m*, which is selected as MPR by its neighbors, periodically announces the information about who has selected it as MPR. However, in the existing work there are no sufficient criteria to form MPR nodes. Therefore, more effective measures are required to differentiate different nodes within a MANET.

#### **2.4.1.1.1 Structure and Data flow in OLSR**

Figure 2.4 [1, 12] shows the structure of OLSR for flowing a particular input data and relations of message processing, message generation and route calculation components in the routing process. OLSR uses three kinds of messages: HELLO, Topology Control (TC), and Multiple Interface Declaration (MID). A HELLO message is sent periodically to all neighbor nodes. It contains information about neighbor nodes, the nodes it has chosen as MPRs, and a list of neighbors for whom bidirectional links have not yet been confirmed. Every node periodically floods, using the multipoint relying mechanism, the network with a TC message. This message contains the node's MPR selector set. A MID message is used for announcing that a node is running OLSR on more than one interface. The MID message is flooded throughout the network by the MPRs.

OLSR receives HELLO, MID, and TC messages and then the HELLO messages from the input trigger updates in the link set, neighbor set, and 2 hop neighbor set and then recalculation of the MPR set is performed. Finally the MPR selector set is updated according to information received

in HELLO messages. Received TC messages trigger updates in the topology set while the MID set is updated upon receiving MID messages. All received messages will also be registered in the duplicate set if not already registered. Finally, route calculation is performed based on information retrieved from the neighbor set, the 2 hop neighbor set, the TC set and the MID set.

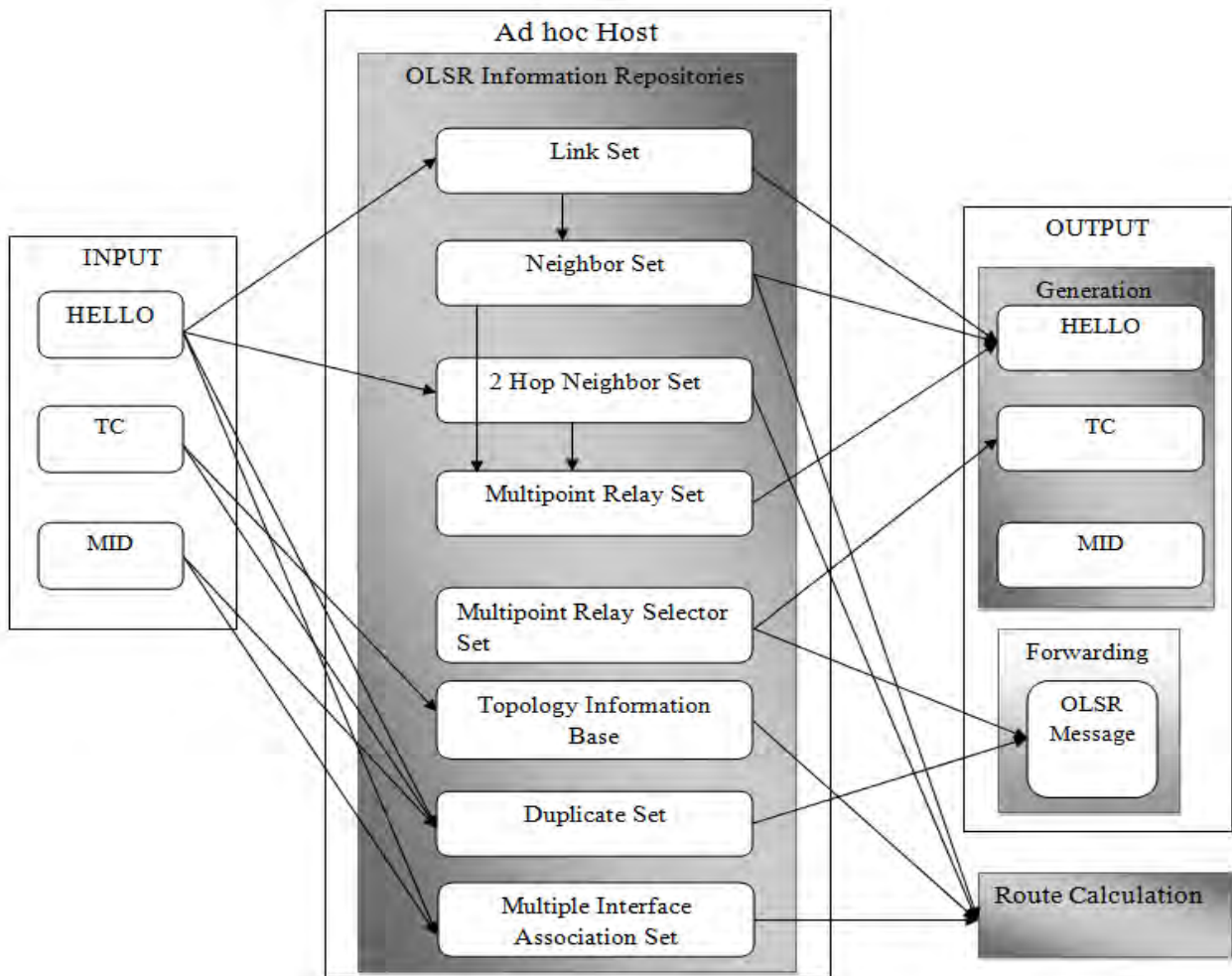


Figure 2.2: Data Flow in OLSR Protocol

### a. Hello Message

To supply the necessary information for link sensing and (one and two hops) neighborhood discovery a node periodically emits HELLO messages. Through the exchange of these messages the link set and the information in the neighbor node is built. These messages are generated and emitted independently for each interface participating in the network. For each different neighbor and link type combination (link code) a list of addresses with interfaces belonging to this link

code is advertised. HELLO messages have local scope and are exchanged periodically between neighbor nodes only, essentially tracking the status of links between neighbors.

#### **b. MID message**

If a node has more than just one interface it announces these additional interfaces periodically to the other nodes by emitting MID messages. As the nodes main address is already included in the originator address of the message header only the additional interface addresses have to be announced. Based upon this information the Multiple Interface Association Information Set is built in the receiving node.

#### **c. TC Message**

A node selected as MPR advertises its advertised neighbor set to the network by emitting TC messages. The message contains a sequence number which is updated every time the advertised neighbor set has changed. Compared to HELLO messages, TC messages have larger scope and are emitted periodically to diffuse link state information throughout the entire network.

#### **d. OLSR Information Repositories**

As a link state protocol, OLSR maintains state by keeping a variety of databases of information. These information repositories are updated upon processing received messages and the information stored is used when generating such messages. OLSR information repositories contain the following data:

- **Link Set:** This repository maintains the state of links to neighbors. It contains pairs of interface addresses and the corresponding times until when this link can be considered symmetric, asymmetric or when it has to be completely removed. These times have to be updated upon reception of a HELLO message from the corresponding node.
- **Neighbor Set:** All registered one hop neighbors are recorded here. The data is dynamically updated based on information in the link set. Both symmetric and asymmetric neighbors are registered. The neighbor set keeps the list of neighbors of the node. Based upon the link connecting the two nodes a neighbor is either classified as a symmetric or as a non symmetric neighbor.

- **2-Hop Neighbor Set:** All nodes, not including the local node, that can be reached via a one hop neighbor is registered here. Notice that the two hop neighbor set can contain nodes registered in the neighbor set as well. The two hop set describes the two hop neighborhood of a node. It stores a list of node pairs describing which two hop neighbors can be reached through which symmetric one hop neighbor.
- **Multipoint Relay Set:** All MPRs selected by the local node is registered in this repository.
- **Multipoint Relay Selector Set:** All neighbors that have selected the node as a MPR are recorded in this repository.
- **Topology Information Base:** This repository contains information of all link state information received from nodes in the OLSR routing domain.
- **Duplicate set:** This database contains information about recently processed and forwarded messages. So this information avoids reprocessing or re-forwarding of the same message multiple times.
- **Multiple Interface Association Set:** This dataset contains information about nodes using more than one communication interface. All interface addresses of such nodes are stored here.

#### e. Forwarding OLSR Packets

To establish and maintain the information of OLSR information repositories a number of different OLSR messages are defined and exchanged periodically by the nodes participating in the network. As we see in Figure 2.5 [1, 12], OLSR packet format, OLSR packets have a packet header consisting of the packet length and a packet sequence number maintained independently by each interface of the OLSR node. The packet body consists of one or more OLSR messages which are preceded by a message header for each message. The message header contains the message type, the validity time, the message size, the originator address, a time to live field, the hop count and a message sequence number. The originator address field contains the main address of the node that initially created the message, independently on which interface the

message left this node. To avoid establishing routing loops and retransmission of already known data each packet and each message carry a sequence number.

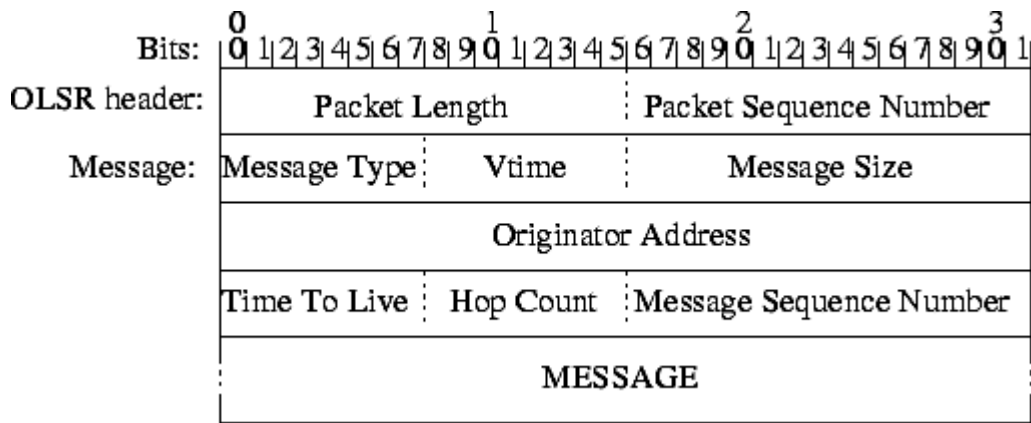


Figure 2.3: OLSR packet Format

#### 2.4.1.1.2 Previous Attempts on the Selection of MPR Nodes

Up on the optimization of link state protocols using selecting flooding scheme which rely on MPR, variant approaches are introduced. The approaches are put forward to improve different aspects of broadcasting performance in MANETs such as the number of forwarding nodes, collision avoidance, efficient power usage and QoS. The schemes can be classified into different groups based on various criteria. Here we classify MPR selection schemes into four groups based on their objectives and ways of MPR selection.

- a. **Pure MPR schemes** [36]: this approach aims to extend the original MPR selections heuristic to reduce transmit collisions and improve the efficiency of power usage in MANETs. The collision problems are mainly due to the large size of the MPR set and the overlapping coverage between MPRs. It can significantly reduce the ratio of successful information transmission thus degrading the overall system performance. Power consumption in MANETs is always an important issue, since efficient use of power in a network cannot only extend the life of batteries, but also increases the ratio of successful communication
- b. **MPR based CDS schemes** [37]: as the previous scheme, these schemes also improve the original MPR selections approaches. It finds a connected dominating set (CDS) based on MPR schemes. A dominating set (DS) is a subset of nodes in the network where every node is either in the subset or has at least one neighbor in the subset. Their aim was

reducing the number of forwarding nodes by generating a CDS based on the existing MPR selection scheme. As a result, the proposed scheme minimizes retransmission overheads in the network.

- c. **QoS based MPR schemes** [35]: in the previous two schemes, MPRs are chosen based on non QoS criteria and each MPR can only propagate information of links between it and its MPR selectors, good quality links may be hidden to other nodes in the network. But, in this scheme the QoS constraints are considered in the network and attempt to find an MPR set that meets the QoS criteria, so that real time applications such as voice and video can be better supported by providing paths with a better QoS metrics such as a larger bandwidth and lower delay. However, finding an MPR set that can guarantee these QoS conditions is the preliminary for better supporting QoS in MANETs.

In [35] two schemes based on QoS measurement are proposed. The first heuristic approach referred to as QMPR-1, has the same initialization steps as the original MPR heuristic, except it changes procedure in order to provide QoS priorities. Instead of higher degree, a node with maximum bandwidth is chosen in case of multiple choices. If equal solution still exists, a node with minimum delay is selected. Then, likely MPRs with large bandwidth are selected, but the improvement is insignificant. The second heuristic, referred to as QMPR-2, is similar to the first one but selects nodes with higher bandwidth as MPRs, and the delay is used when there is a tie. In case of multiple nodes with maximum delay reachability is chosen. This heuristic highlights QoS criteria in the MPR selection; thus, MPRs are chosen based on QoS conditions, so the optimal links are published between a given pair of source and destination.

Another two approaches are proposed in [4, 6, 8, 9] which aim at finding the route with optimal data rate route in the network. In the first approach, the node which has the largest data rate will be chosen as MPR when there are more than one 1-hop neighbors covering the same number of uncovered 2-hop neighbors. In the second approach, the neighbors with best data rate are selected as MPRs until all the neighbors are covered. That is, the link with the highest data rate will be selected first no matter how many 2-hop neighbors it connects to. Thus, more MPRs might be selected for one node in QOLSR than in OLSR, because in OLSR, the 1-hop neighbor that reaches maximum number of 2-

hop neighbors will be selected first. The idea behind the second MPR selection scheme is to select the best bandwidth neighbors as MPRs until all the 2-hop neighbors are covered.

- d. Novel MPR selection scheme [17]:** this scheme still follows the same steps as the original MPR selection but it has made some modification, where for each 2-hop node, the cost function of all of its available paths to the source node and reachability of candidate relay are calculated. As a result, it improves the performance of MPR selection technique based on a hybrid cost function taking into account QoS criteria bandwidth, peer node life time and delay, and avoiding mobility effect of nodes, especially for those selected as MPRs.

However, the approaches of selecting optimal routing paths have many problems, some of them have problem of overhead, delay and others miss in selection quality links. Therefore, the approach followed in this thesis work is expected to compute the best route which is optimal and more effective than other approaches, based on multiple QoS constraints among all the possible routes which will finally come up with better bandwidth utilization, minimizing delay, controlling overhead, and minimizing of transmission error at the best case.

#### **2.4.1.1.3 Challenges of Selecting MPRs**

Even if having MPR technique in OLSR protocol provides us optimizing the routing of packets in the network, the way of selecting MPRs in MANETs is very challenging. Because, as we know MANET nodes in nature are highly mobile, paths are unstable, and they are updated frequently. Nodes are communicating through wireless links with limited transmission range. Each message sent by a node will be received only by the nodes located within the specified communication range. Since, as the nodes are mobile, the criteria that we stated in MPR selection process may not be stable.

The decision of how each node selects its MPRs is essential to determining the optimal routing path. By any means the node having better QoS constraints should be selected as MPR [30]. In some MPR selection process, the node selects the neighbor that covers the most unreached 2-hop neighbors as MPR. The strategies may limit the number of MPR in the network, and ensure that the overhead is as low as possible. But, in QoS routing by such MPR selection mechanism the good quality of links may be hidden to other nodes in the network. Moreover, many researchers

are proposing different MPR selection criteria, but none of them are adequate enough to select an appropriate MPR node in the network. So due to insufficient selection criteria of a node providing efficient QoS routing using OLSR protocol is very challenging.

#### **2.4.1.2 Destination Sequenced Distance Vector Routing Protocol (DSDV)**

DSDV [20, 28] is a modification of conventional Bellman-Ford routing algorithm. This protocol adds a new attribute, sequence number, to each route table entry at each node. Routing table is maintained at each node and with this table a node transmits the packets to other node stations in the network. These stations list all the available destinations and the number of hops required to reach each destination in the routing table. It is designed to address the looping problem of the conventional distance vector routing protocol and to make the distance vector routing more suitable for ad hoc networks routing. DSDV requires that each mobile station in the network must constantly advertise to each of its neighbors, its own routing table. Since the entries in the table may change very quickly, the advertisement should be made frequently to ensure that every node can locate its neighbors in the network. This agreement is placed to ensure the shortest number of hops for a route to a destination. In this way the node can exchange its data even if there is no direct communication link. The data broadcasted by each node will contain its new sequence number, destination address, the number of hops required to reach the destination and the new sequence number, originally stamped by the destination.

Surveys on the routing protocols showed [5, 13, 20, 28] the performance of DSDV is high in networks which have less number of nodes and less mobility. When the number of nodes in the network grows the size of the routing tables and the bandwidth required to update them also grows. These will lead to high overhead which is the main weakness of DSDV. DSDV also poses a period of convergence before which routes will not be known and packets will be dropped. In addition, in DSDV routing loops can occur while the network is reacting to a change in the topology. It has a high degree of complexity especially during link failure. Fluctuation is another problem of DSDV. In some simulation studies [20, 28], DSDV is much more conservative in terms of routing overhead but because link breakages are not detected quickly more data packets are dropped.

## **2.4.2 Reactive Routing Protocols**

In bandwidth starved and power starved environments, it is interesting to keep the network silent when there is no traffic to be routed. Reactive routing protocols do not maintain routes, but build them on demand [20, 22, 25]. A reactive protocol finds a route on demand by flooding the network with Route Request packets.

These protocols have the following advantages:

- No big overhead for global routing table maintenance as in proactive protocols.
- Quick reaction for network restructure and node failure.

Even reactive protocols have become the main stream for MANET routing, they still have the following main disadvantages:

- High latency time in route finding.
- Excessive flooding can lead to network clogging.

Therefore, these routing protocols perform better QoS in terms of packet delivery ratio and incur lower routing overhead especially in the presence of high mobility [26]. Compared with the other routing protocols, they need relatively unconditional low storage, and the routes are available only when they are needed. However, because of high latency time in route finding process reactive routing protocols are not suitable for most time sensitive applications in which delay is a critical issue. Some of the reactive routing protocols for MANETs are AODV, DSR, and DYMO.

### **2.4.2.1 Ad-hoc On-demand Distance Vector Routing (AODV)**

AODV [21] uses on demand approach to discover and identify a specific route. When a node requires sending data, AODV uses route discovery using control messages like route request (RREQ) and route reply (RREP) to find the route to the destination. In AODV neighbor nodes store the route information of their next hop neighbor. This enables AODV to evaluate the shortest distance and safe path. To discover a path a source node broadcasts a route request message to its immediate neighbors. Neighbors in-turn send the route request packet to their neighbors. This process continues until the destination is reached. When the RREQ packet

reaches a destination, the destination node replies back with RREP and window size for data transmission. Once the data packet is transmitted the route information will be cleared. AODV discovers and identifies a route only when a node requires sending or receiving data. During error while transmission or link failure a route error (RERR) message will be generated and sent to the source node to find an alternative path. The main advantage of AODV is that a route is discovered and identified on demand. AODV faces severe drawback as intermediate nodes may forward to unreliable routes if the source sequence number is very old and the intermediate nodes have a higher, but not related to the latest destination sequence number.

AODV is appropriate for QoS routing when a loop free and up to date route is required. In this routing protocol, to know their current destination route, every mobile node preserves routing table of next hop. Once a source node desires to establish a communication session, it initiates to send packets to the destination if it has a current route to the destination in its routing table. Otherwise, it initiates a path discovery process by broadcasting a route request message.

As on demand routing protocol [20, 21], AODV uses periodic broadcast of Hello Message to track neighboring nodes. This periodic propagation causes network overhead in AODV. In AODV a routing path to a particular packet is discovered at time of needs. This initial search latency may degrade the performance of interactive applications. Similarly the quality of path is not known prior to call setup. It can be discovered only while setting up the path. Moreover quality of path must be monitored by all intermediate nodes in an active session at the cost of additional latency and overhead. That makes AODV quite unsuitable for real life time applications. AODV cannot utilize routes with asymmetric links between nodes and thus requires symmetric links. Nodes in AODV store only routes that are needed. Nodes use the routing caches to reply to route queries. These results in uncontrolled replies and repetitive updates in hosts caches yet early queries cannot stop the propagation of all query messages which are flooded all over the network.

#### **2.4.2.2 Dynamic Source Routing (DSR)**

This is an on-demand source routing protocol. In DSR [22, 24], the route paths are discovered after the source sends a packet to a destination node in the ad-hoc network. DSR requires no periodic updates of any kind at any level within the network. It uses source routing through which sender knows the complete hop by hop route to the destination. These routes are stored in

a route cache. A data packet carries the source route in the packet header. DSR consists of two mechanisms, route discovery and route maintenance [25]. Route discovery functions by flooding the network with route request packets. Each node receiving a route request packet rebroadcasts it unless it is the destination or it has a route to the destination. The route carried back by the route reply packet is cached at the source for future use. For route maintenance, whenever a link on a source route is broken, the source node is notified using a route error packet.

In MANETs, DSR can be chosen to provide soft QoS guarantees in different areas of MANET applications when better QoS parameters like reliability, packet delivery, overhead, etc. should be taken into account for routing of packets. The protocol provides a reliable route for packet transmission with a minimum network overhead.

Due to source routing DSR has major scalability problem [22, 27]. Nodes use routing caches to reply to route queries. This results in uncontrolled replies and repetitive updates in hosts caches. In addition, early queries cannot stop the propagation of all query messages which are flooded all over the network. Therefore when the network becomes larger, the control packets and message packets also become larger. This could degrade the protocol performance after a certain amount of time.

#### **2.4.2.3 Dynamic MANET on Demand Routing Protocol (DYMO)**

DYMO is reactive and multi-hop unicast routing technique [23]. The main operation of this routing protocol is performing route detection and route preservation. During route detection, the sender node initiates route request throughout the network to identify the destination node in the network. The destination node in-turn replies back to the source with route reply [26]. However, the destination node may also use a different route to reach the source node. It is not mandatory for the source and destination to use the same path for communication. Route request and Route reply are passed across the network by unicast hop-by-hop communication. In DYMO, route maintenance is performed as 2 operations. To protect the existing routes, DYMO routers lifetime is increased with every successful delivery of a packet. In order to identify the changing network topologies, DYMO routes will be monitoring the entire network links through which network traffic is forwarded. When a packet reaches any node by forwarding and if the node has no information of the destination, then the node informs the source node with route error. A Route

Error is an error packet send to the source or destination to notify that the path or link is invalid or missing.

### **2.4.3 Hybrid Routing Protocols**

These types of protocols combine the advantages of proactive and reactive routing protocols [28]. The routing is initially established with some proactively prospected routes and then serves the demand from additionally activated nodes through reactive flooding. The choice for one or the other method requires predetermination for typical cases.

The main disadvantage of hybrid routing protocols is that the nodes that have high level topology information maintain more routing information, which leads to more memory and power consumption.

An example of such a protocol is the Zone Routing Protocol (ZRP). ZRP divides the topology into zones and seeks to utilize different routing protocols within and between the zones based on the weaknesses and strengths of these protocols [28].

The major drawback of proactive routing protocols is that excess bandwidth is utilized to maintain routing information. However, reactive routing protocols initiate unwanted delay in the network by increasing route request and route reply wait time. Reactive routing protocols cause major energy consumption to broadcast route request and route reply. The ZRP also has problems of network delay and excess energy utilization. In Ad-Hoc networks, if network congestion is most likely to occur, the path will be changed or packets will be diverted to nearby nodes. In ZRP route information is maintained only with sensor nodes which stay on the routing zone. In ZRP a node discovers and identifies its zone through a proactive scheme called Intra zone Routing Protocol (IARP). For nodes outside the routing zone, Inter zone Routing Protocol (IERP) is responsible for reactively discovering routes to destinations. IERP identified and maintains a route record of nodes that exist in the routing zone. This will reduce unnecessary broadcast of route request to identify the nearest neighbor.

ZRP limits the proactive overhead to only the size of the zone [28]. It also limits reactive search overhead to only select border nodes. Potential inefficiency may occur when flooding of the RREQ packets goes through the entire network. To some extent this protocol can provide a better

solution in terms of reducing communication overhead and delay. But this benefit is subjected to the size of a zone and the dynamics of a zone. ZRP does not provide an overall optimized shortest path if the destination has to be found through IERP. Moreover with the increase of network size ZRP could create unpredictable large overhead. In ZRP each path to a destination may be suboptimal. This also means that each node will have higher level topological information. Thus poses a higher memory requirement and an extra burden on the network resources.

## 2.5 Comparison on the Properties of MANETs Routing Protocols

*Table 2.1: Properties of MANETs Routing Protocols*

Characteristics	MANETs Routing Protocol					
	Proactive		Reactive			Hybrid
	OLSR	DSDV	AODV	DSR	DYMO	ZRP
Organization of the network	Flat	Flat	Flat	Flat	Flat	Flat
Route availability	Always available	Always available	Computed as per need	Computed as per need	Computed as per need	Depends on location of destination
Routing information	Keep stored in table	Keep stored in table	Doesn't store	Doesn't store	Doesn't store	Depends on requirement
Route freshness	Up-to-date	Up-to-date	Not Up-to-date	Not Up-to-date	Not Up-to-date	Up-to-date inside each zone
Data forwarding type	Hop to hop	Hop to hop	Hop to hop	Hop to hop	Hop to hop	Hop to hop
Update transmitted to	MPR node	Neighbors	Neighbors	Neighbors	Neighbors	Neighbors
Frequency of	Periodical	Periodical	Periodical	Periodical	Periodical	Periodical

Characteristics	MANETs Routing Protocol					
	Proactive		Reactive			Hybrid
	OLSR	DSDV	AODV	DSR	DYMO	ZRP
updates			as needed	as needed	as needed	inside each zone
Supports asymmetric	Yes	No	Yes	No	Yes	No
Route discovery	Periodic	Periodic	On-demand	On-demand	On-demand	Periodic inside zone
Need of Hello message	Yes	Yes	Yes	No	Yes	Yes
Multi-hop wireless support	Yes	Yes	Yes	Yes	Yes	Yes
Multiple routes	No	No	No	Yes	No	No
Redundant route	No	No	No	No	No	No
Node overhead	Medium	High	Medium	High	Medium	Medium

Table 2.1 provides the characteristic features of some of the well known routing protocols and described which protocols may perform best in large networks to maintain routing information. The protocols we discussed in this Chapter have their own characteristic features and performance parameter combinations where they outperform their competitors. Still mobile ad hoc networks have posed a great challenge for researchers due to changing topology in the routing processes, and none of the protocols is fully efficient for satisfying QoS demanding application.

Surveys [5, 10, 13] on different routing protocols have been conducted to recommend a better routing protocol for QoS routing in mobile ad hoc networks. Guaranteeing delivery and the capability to handle dynamic connectivity of nodes are the most important issues which are considered in the surveys of routing protocols. Once there is a path from the source to the

destination for a certain period of time, the routing protocol should be able to deliver data via that path. If the connectivity of any two nodes changes and routes are affected by this change, the routing protocol should be able to recover if an alternate path exists. However, mobile ad hoc networks suffer with different issues like bandwidth constraints and limited power of mobile devices. Therefore, there is a need of a routing solution that can not only offer a better routing solution but also addresses some routing related issues like end to end delay, overhead, throughput optimization, transmission errors, etc.

## 2.6 QoS and QoS Routing in MANETs

### 2.6.1 Quality of Service (QoS) in MANETs

Quality of Service (QoS) in MANETs [3, 5, 7, 8] is defined as a set of service requirements that need to be met by the network while transporting a packet stream from a source to its destination. The network is expected to guarantee a set of measurable pre-specified service attributes to the users in terms of end to end performance such as bandwidth requirement, probability of packet loss, the variation in latency (jitter), route acquisition delay, communication overhead, scalability, etc. However, as a result of evolution in multimedia technology and the commercial interest of companies, quality of service in mobile ad-hoc networks has become an area of interest. Because of various requirements of different applications, the services required and the QoS parameters change for each application. For example, for multimedia applications (real time data traffic), the data rate and delay are the key factors where timing is a critical issue. Generally, QoS parameters can be grouped in to three categories:

- a. **Additive:** It is the sum of the metrics on all links along the path like end to end delay and jitter are additive QoS parameters. For example, end to end delay of a path is equal to the summation of delays at each link.
- b. **Multiplicative:** It represents the product of the metric values on all links over a path. For example, probability of packet loss  $p(u, v)$  for a packet to reach  $v$  from  $u$  is the product of packet loss probabilities at each intermediate individual link.
- c. **Concave:** It considers the minimum metric value over a path. Parameters like bandwidth, security and end to end reliability are concave parameters. Bandwidth along a path from  $u$  to  $v$  is the minimum bandwidth along the links on the path.

Therefore, in MANET nodes cooperative and intermediate nodes participate in source to destination route formation. The required QoS parameter on a given path can be calculated by one of the given ways depending on the nature and behavior of the QoS parameter. However, it is shown that in multi hop environment to consider a pair of two multiplicative or additive or one additive and one multiplicative constraint for satisfying QoS needs are Nondeterministic Polynomial time (NP) Completeness problem. In normal practice for reducing combinatory explosion one concave constraint (like bandwidth) and one additive constraint (like end to end delay) or multiplicative constraint (like packet loss) are considered for QoS guarantee.

### **2.6.2 QoS Routing in MANETs**

Support for QoS is an important and desirable component of MANETs. Several important research issues and open questions need to be addressed to facilitate QoS support in MANETs. Capacity estimation, route discovery, route maintenance and feasible path selection are issues that require further exploration.

One of the key issues in QoS routing is finding a feasible path that satisfies the QoS constraints of a given MANET application. However, in MANETs due to node mobility, limited resource constraint, multi-hop communications, contention for channel access, and lack of central coordination, QoS routing is very challenging. In the past decade, several approaches [5, 10, 13, 20] proposed various routing algorithms with QoS support for MANETs. However, none of them is adequate enough to incorporate all of the available QoS parameters for an efficient routing of a packet. Figure 2.4 shows the difference quality of video frame in video streaming with and without QoS support.

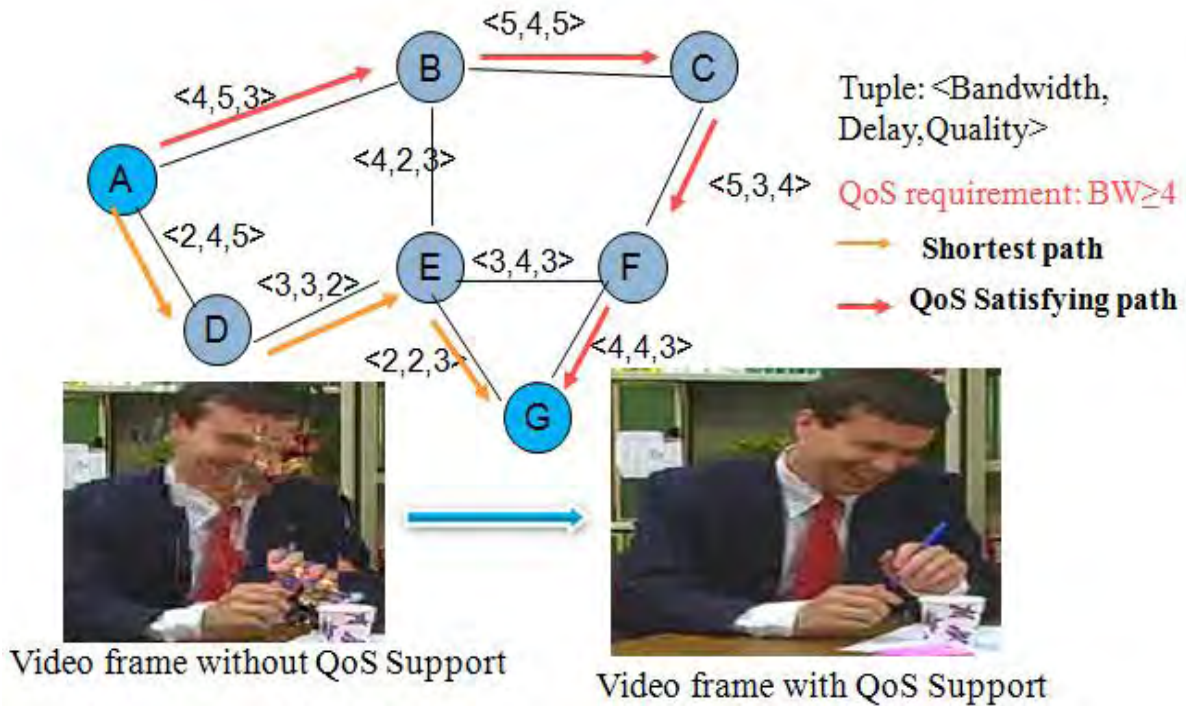


Figure 2.4: Sample Video Streaming

Thus, routing protocols may need to offer different ways or methods to select the best path based on the QoS metrics on the discovered paths. Some constraints can be relevant to one service but not to another. Each service has a set of QoS constraints that has to be met in order to deliver that service; thus, it is important to define these constraints and the minimum/maximum value for each constraint to be used in the routing process.

## **Chapter Three: Related Work**

Recently, wireless communication between mobile users is becoming more popular than ever before. They are able to support robust and efficient operations by incorporating the routing functionality into mobile hosts. Because of the rising popularity of multimedia applications and potential commercial usage of MANETs, QoS support in Ad-Hoc networks has become a topic of great interest in the wireless area, and several research directions are proposed to enhance the services provided by MANET applications. In this Chapter, we have categorized the works done so far based on route discovery: QoS routing using proactive, reactive and hybrid routing protocols.

### **3.1 QoS Routing Using Proactive Routing Protocols**

In the following section we will summarize the works which are conducted on the most well known proactive routing protocols for providing QoS routing service.

#### **QoS routing using OLSR Routing Protocol**

In the last decade several researchers proposed OLSR routing protocol for applications that require QoS. Here we summarize those that are relevant and related to our study.

In [4] routing protocols that support QoS are evaluated using simulation tools and a new algorithm is proposed that will improve the performance of existing MANETs routing protocols for QoS demanding applications such as video conferencing, voice over IP and multimedia streaming. In this work, an efficient routing protocol is proposed, but the algorithm finds the shortest path among the neighbors by considering only a limited constraint like bandwidth. MPR node selections were done only by considering the neighbors that cover a maximum of 2-hop neighbors and the node having the highest bandwidth. This may reduce the number of MPRs on the network and ensures that the overhead is as low as possible. However, the approaches do not guarantee QoS routing for time sensitive applications in which delay is a critical issue. In the routing process there may be a possibility of node overlapping and the best routing paths may be hidden. Also there is no clear explanation of how the routing table is computed. In conclusion, the author conducted an experimental test using NS2 simulator and showed the performance of QoS aware OLSR and its corresponding best effort OLSR version protocol under different network density and speed. QoS aware OLSR is found better than best effort OLSR which is

relatively suitable in delay bounded applications using packet delivery fraction, average end to end delay and minimized overhead.

In [6] a heuristic algorithm is developed to improve the performance of OLSR protocols in the bandwidth QoS aspect. In this work, the algorithm allows OLSR to find the maximum bandwidth path among the neighbor nodes and showed through simulations that these heuristics do improve the performance of OLSR in a static network. But, in static network the movement of nodes and changing bandwidth do not have a big impact on the performance of the network. The authors showed the optimality of the algorithm and implemented it in OPNET based on the provided OLSR model. The algorithm is evaluated and the authors compared the performance of the QoS OLSR versions and the original OLSR protocol and also analyzed the benefit and the achievements gained for QoS routing. However, in this work the algorithm did not consider constraints other than bandwidth. The authors did not claim on reducing the communication overhead toward providing efficient QoS routing. The aim of the MPRs during the broadcast phase is to forward packets effectively by reducing redundancy of traffic. However, there is a possibility of packet loss and redundancy when two MPRs relay a message at the same time to the same destination. So, this work did not consider overlapping between MPRs.

In [8] the authors used different metrics to provide QoS enhancements in OLSR protocol. The proposed combined metric attempts to make use of available resources to find the most optimal path based on mobility, bandwidth, and energy parameters. This work mainly focused on solving the routing issues based on the assumption that an underlying mechanism is there to gather the necessary information about the individual metrics. In order to improve the performance of ad hoc routing protocols through maximizing network throughput, the authors managed the network bandwidth by taking into account the constraints of energy and mobility. The work has been evaluated in terms of routing load, packet delivery fraction, and end to end delay. However, MPR node selection and routing table calculation criteria are not clearly defined.

In [9] the authors proposed a solution taking into account radio interferences in mobile ad hoc network routing and optimizing flooding. This solution is based on a modified version of the OLSR routing protocol that considers bandwidth requests and radio interferences in the route selection process while providing a very efficient flooding. A comparative performance evaluation based on NS simulations showed that despite the overhead due to QoS management,

this solution outperforms classical OLSR in terms of QoS perceived by users (e.g., bandwidth amount granted to a flow and delivery rate). The efficiency of the optimized flooding is equal to that provided by the native version of OLSR. However, delay estimation is not done and bandwidth estimation method is missing.

In [15] a heuristics for highly efficient selection of MPR in OLSR protocol is proposed. MPR selection is one of the most important and critical functions of OLSR protocol. This paper proposes a Fuzzy logic based novel routing metric for MPR selection based on the energy, stability, and buffer occupancy of the nodes. An algorithm is designed to cope with these constraints in order to find quality MPR (QMPR) that guarantees QoS in OLSR. The aim of this paper is to formulate, build, evaluate, validate and compare rules for QMPR selection using fuzzy logic. It is shown that a node having higher energy-level and stability has the highest probability to be elected as a QMPR. Otherwise, if the energy and stability of a node is low then the probability of the node to be selected as MPR will also be low. According to the work, node stability in the network with the energy is the most crucial factor for the QMPR selection and to make the OLSR protocol a better one for a network having longer life time. The work has been validated that proposed composite metric (based on energy, stability and buffer occupancy) to select a more stable MPR than the existing one. By mathematical analysis and simulation, it is shown that efficiency of OLSR protocol has been improved using this new routing metric in terms of energy efficiency and network life time.

In [13] a survey of routing protocols that support QoS in MANETs has been done. The paper presented the issues involved with QoS aware routing and an overview and comparison of existing QoS aware routing protocols. The comparison between the routing protocols was performed in terms of their support for node mobility, routing overhead, and scalability of the network. In addition, to fully support QoS aware routing, open issues which can be worked in the future like route discovery, resource reservation, route maintenance, delay estimation, etc. are discussed.

In [14] a new algorithm called Necessity First Algorithm (NFA) was proposed to select the MPRs. By selecting MPRs from the necessity of selecting, the algorithm improves the greedy algorithm to a certain extent. The work is evaluated and the final results of simulation show that the number of MPRs selected by NFA could reduce overhead and save resources of a network.

As the improvement scenarios show, NFA is an algorithm more suitable for networks with higher density. This work only focused on minimizing the number of MPRs and reduction of overhead in the network.

The author in [11] made a survey on the different routing protocols and presented the advantages and limitations of each routing protocol. OLSR protocol reduces the message overhead as compared to a classical flooding mechanism, where every node retransmits the first copy of the message it receives. In OLSR, link state information is generated only by nodes selected as MPRs.

In [16] a heuristic algorithm is developed to determine a feasible path between two end points by considering multiple constraints so that a set of QoS path constraints can be satisfied while selecting an optimal path of a network. The experimental result shows that the algorithm is very efficient for solving large scale multiple constraint path selection problems and it has a good performance on several different network topologies. But MPR node selection and routing table calculation criteria are not clearly defined.

In [18] the authors designed a heuristic algorithm for choosing a predicted MPR. It selects a one hop neighbor, which reaches the maximum number of uncovered two hop neighbors as MPR. If there is a tie, the one with higher degree is chosen. In the paper, the authors developed a predictive mobility model that provides predictive routes to access mobile nodes through existing and previous multipoint relays. Thus if a specific node in the MANET wants to send some message to a mobile node, it gets the addresses for both previous and predicted MPRs to achieve reliable communication. The packets destined to a mobile node are processed by both MPRs, and the mobile node receives those packets from any of two MPRs, hence ensuring minimum chances of data or packet loss for that mobile node. The key contribution of this paper is establishing a reliable communication on MANET nodes by designing an approach that will sense the mobility of the node using local link information. If a node becomes mobile, the proposed algorithm enables the network to access such a mobile node through previous as well as predicted MPRs. Finally, the authors showed that the predictive routes in routing tables guarantee minimum chances of data or packet loss by deploying the concept of redundant MPRs.

In [19] the authors analyzed MPR selection in OLSR routing protocol with and without QoS support. The analyses for MPR selection is performed based on QoS metric such as available

bandwidth, delay, packet loss rate, and energy. The simulation result showed that the number of MPRs with QoS support is higher than the number of MPRs without QoS support. Thus, it recommended that for flood optimization or to minimize the overhead, it is better to use MPR without QoS support. But, to build efficient routes with QoS metrics it is better to use MPRs that supports QoS.

In [31], fish eye approach is applied on OLSR protocol. The approach maintains entries of nearby nodes in the routing table, they are updated and exchanged with neighbors more frequently (to reduce the update message size). Thus, the frequency of topology information updates decreases as the distance increases. This optimization is justified by the fact that a vague idea of the node location is enough to forward data packets to far destination. As the data packets go closer to the destination, the routing information becomes more and more accurate and nearer nodes can route data packets more precisely. The accuracy of route increases as packets get closer to the destination. The main drawback of this approach is, as the distance of remote nodes increases the accuracy of the routing information decreases.

In [32], tree clustering technique is applied on OLSR. The technique improves scalability of nodes and introduces hierarchical routing. The clustering algorithm is based on the connectivity of nodes. Each cluster is referred to as a tree and each cluster head is referred to as root of its tree. To route to other trees, OLSR is applied on the cluster topology and exchanging of messages are done by using cluster heads. When a node needs to send data to a node outside its tree, it first sends the traffic to its root which then forwards the traffic to the destination node following the cluster path. This may overload the cluster heads and produce suboptimal paths.

In [33], in order to reduce the control overhead and routing table size, the authors propose clustering approach on OLSR protocol. The approach does not depend on a specific clustering algorithm but is assumes that a clustering mechanism is being executed in the ad hoc network. The protocol applies regular OLSR inside each cluster and TC messages are forwarded only within the cluster. In this approach two new messages cluster hello and cluster TC messages are defined to emulate the behavior of an OLSR node by a cluster. This may generate additional overhead of the network. In [31, 32, 33], other than applying clustering techniques on top of link state routing protocol, ways for improving OLSR routing protocol like selection of MPR, computation of routing path, and forwarding of packets is not discussed.

In [40] the authors proposed a novel heuristic based clustering approach that is adapted to be implemented in standard OLSR. The algorithm allows construction of disjoint clusters, their maintenance, and election of cluster head on ad hoc networks. In cluster construction the radius is fixed at 2 and information of the 2-neighborhood is available for each node. Computing is made locally, thus, the algorithm is inexpensive in terms of messages and latency. It behaves like standard OLSR in intra cluster and involves only nodes which form the connected dominating set in inter cluster. Thus, it significantly reduces the amount of control traffic. The criterion of electing cluster heads focused on a density of nodes without considering other basic constraints like mobility, energy, etc. The work is evaluated and compared to standard OLSR and showed that it outperforms in terms of average end-to-end delay, control routing overhead, and packet delivery ratio.

Generally, in OLSR, the algorithms which are designed in the works [4, 6, 35, 36] are not efficient enough for MPR node selection, route table computations, and forwarding of packets, since the approaches have limitation like latency, optimality, and failure tolerability toward providing efficient QoS routing. To efficiently compute the routing table, to quickly select appropriate MPR node and routing path, and to periodically propagate update information between MPR nodes, a new algorithm is required. The existing algorithms make MPR node selection only by considering number of neighbor's node capacity and bandwidth among each neighbor. But, other constraints like link quality, delay, and minimum overlap should be taken into account to keep better MPR nodes. Also in some previous works, each network node makes MPR node selection when the node  $m$  which is selected as MPR is not anymore part of the network. But, it is better to make MPR selection of each node whenever any change of node performance like bandwidth, delay, etc., happen on the network.

### **3.2 QoS routing using Reactive Routing Protocol**

Over the last few years, many reactive routing protocols for MANETs have been proposed. Here we have reviewed the most well known types of reactive routing protocols that will provide us a better QoS routing in MANET applications.

#### **3.2.1 QoS routing using AODV Routing Protocol**

Some important works which are conducted for QoS routing using AODV are discussed as follows:

In [20] the authors made a comparative study and performance evaluation of reactive quality of service routing protocols that are best suited for MANETs. The study has been done by considering parameters like average jitter, overhead, throughput and total number of packets sent and received. The results were analyzed using simulation method and QUALNET simulator was used for the analysis. Finally, the authors concluded that compared to most reactive protocols AODV is better for QoS routing. However, this routing protocol is not suitable for multimedia applications in which average end to end delay is taken as a critical issue.

In [29] the authors proposed an approach and summarized some existing schemes for QoS aware routing protocols for MANETs by considering two important metrics: data rate and delay. Evaluations are presented by doing simulations using NS2 with both QAODV and AODV routing protocols. Different data rates and moving speeds are tested in order to see the performance of two simulated protocols. The results show that the QAODV outperforms the AODV in terms of end to end delay when traffic on the network is high. They also found that when the network begins to be saturated, the route discovery and maintenance process become more important.

In [21] the author proposed cross layer approach to improve the performance of MANET routing protocols particularly AODV protocol. The proposed model utilizes signal to noise ratio measurements along the routing path and selects the path with high quality of service rather than the path with minimum number of hops. In the new routing approach, when a route request packet arrives at the destination or an intermediate node with a route to the destination, a route replay packet will be generated. This reply packet is then sent back to the source node following the reverse route contained in the route request packet. Each intermediate node will update the

signal to noise ratio (SNR) value if its link value of SNR is lower than the existed recorded value in the route reply packet. If the SNR value of its link is greater than the recorded value, the node will not update the value. The process will continue until the route reply packet reaches the source node. Now, the source node will select the route based on the value of best of worse available value of SNR. The work is experimentally tested and simulation results show that the proposed model gives better performance in terms of delivery ratio, delay and packet drop compared to the existing AODV protocol.

In [30] the authors analyzed the performance of various reactive routing protocols based on fuzzy inference system. In this paper, fuzzy inference system offers to accept multiple input constraints like energy, number of collision, end to end delay and number of hops for finding an optimal routing path. Finally, the simulation result shows that the proposed system enhances the performance of AODV routing protocol on real time applications.

### **3.2.2 QoS routing using DSR Routing Protocol**

Some of the works which are conducted on DSR are summarized as follows.

In [22] the authors proposed a distributed Multi Path Dynamic Source Routing protocol (MP-DSR) for wireless ad-hoc networks to improve QoS support with respect to end-to-end reliability. In this paper, in order to select a subset of end-to-end paths to provide increased reliability of routes, a new QoS metric, end-to-end reliability, is incorporated on the existed one. A simulation study is performed on the proposed approach and it shows that MP-DSR achieves a higher rate of successful packet delivery than existing best effort ad-hoc routing protocols such as DSR.

In [24] a new QoS-DSR strategy for reactive route discovery was proposed. The strategy is based on two QoS parameters, minimum bandwidth requirement and maximum allowable end to end delay. DSR routing protocol was used as a basis for implementing the proposed route discovery mechanism. Using NS2 network simulation the proposed approach was evaluated on 50 nodes and the result shows that in all comparisons of DSR and QoS-DSR, the proposed approach (QoS-DSR) exhibits reduced end to end delay while maintaining high packet delivery ratio.

In [25] the authors proposed Ant Based Dynamic Source Routing (ADSR) algorithm to provide QoS support routing, such as acceptable delay, jitter and energy in the case of multimedia and

real time applications. The proposed protocol selects a minimum delay path with the maximum residual energy at nodes. The performance of DSR and ADSR are analyzed using NS2 simulator and the result shows that the proposed algorithm is better than the existing ones in terms of delay, energy, jitter and throughput. Even if ADSR performs well in route discovery with dynamic changes in the network topology and produces much better throughput with very low variance in the delay, it results in slightly higher routing overhead than DSR.

In [27] the authors proposed a QoS model for DSR protocol by adding extension related to bandwidth metric to its structure to support certain aspect of QoS capabilities. The change that had been made in this paper was bandwidth availability along the path from the source to the destination that can satisfy the requirement. In order to test the proposed model, a simulation is implemented using NS2 and different scenarios were tested to see the performance of the modified protocol compared with the original DSR protocol. The results show that adding QoS to routing protocols is important to optimize the performance of traffic on the network especially in real time traffic.

### **3.2.3 QoS routing using DYMO Routing Protocol**

In MANETs, as we observed from the literature, DYMO is more suitable than most reactive routing protocols to perform an efficient routing. It may need to provide different level of QoS to support different types of applications. Some important works which conclude the appropriateness of this protocol are discussed as follows:

In [23] the authors simulated the existing DYMO and analyzed its performance based on various simulation metrics. In the paper, a network of size 40 nodes has been considered for simulation. Similarly data has been collected for other existing routing protocols such as AODV, DSDV and DSR to compare between these in terms of various metrics and to study the performance of every reactive protocol compared to DYMO. The simulation result shows that DYMO performs better in all factors like routing overhead, throughput, packet delivery fraction, and average end to end delay than all other reactive routing protocols.

In [26] the authors evaluated AODV, DSR, and DYMO. Performance of each routing protocol has been analyzed and evaluated based on different number of nodes over different speed and different pause time and they found that DYMO is a better routing protocol than DSR and

AODV for MANETs with respect to QoS parameters, i.e., throughput, packet delivery ratio, delay, normalized routing load. In terms of routing overhead AODV performs better than others.

### **3.3 QoS Routing using Hybrid Routing Protocols**

As we described in the literature, hybrid routing protocols are appropriate in the area when the advantage feature of both proactive and reactive protocols is required. In the following section we discuss researches which are conducted using hybrid routing protocols.

#### **QoS routing using Zone Routing protocol (ZRP)**

In [28] the authors analyzed the performance of ZRP on various node densities in terms of end to end delay, average jitter and packet loss. As the density of the node increases, the number of neighbors around the node and number of zones in the area increase. Hence, overall delay required by the packet to reach its destination will increase. At the same time the chance of wrong path selection and packet loss also increase. Moreover, when the times required for sharing information between zones vary, the packets reach the destination at different time delay. Finally, the authors concluded that ZRP is suitable for large networks by providing the benefit of both proactive and reactive routing protocols. However, this result is dependent on the type of application in which we use ZRP. If we use it for real time applications like video transmission, in high node density, the performance of ZRP routing will decrease.

### **3.4 Comparison of Routing Protocols in MANETs**

As shown in Table 3.1, based on the surveys [10, 13, 20, 44] we have summarized the comparison between proactive, reactive and hybrid routing protocols while providing a QoS routing in MANETs.

Table 3.1: Comparison of QoS Routing Protocols

QoS Parameter	MANETs Routing Protocol					
	Proactive		Reactive			Hybrid
	OLSR	DSDV	AODV	DSR	DYMO	ZRP
End to End delay	Lower	Lower	Higher	Higher	Higher	Low for local destinations and high for Inter zone
Bandwidth requirement	Medium	High	Low	Low	Low	Medium
Storage Requirement	Higher	Higher	Dependent on no. of route maintained	Dependent on no. of route maintained	Dependent on no. of route maintained	Depends on size of each zone
Throughput	Very good	Good	Good	Good	Good	Poor
Mobility	Good	Good	Very good	Good	Good	Poor
Packet delivery ratio	Very good	Good	Good	Good	Very good	Very good
Loop free	Yes	Yes	Yes	Yes	Yes	Yes
Reliability	Good	Poor	Good	Very good	Very good	Good
Power requirement	High	High	Low	Low	Low	Medium
Overall complexity	Low	High	Medium	Medium	Medium	Medium
Communication overhead	Medium	High	Low	Low	Medium	Medium
Scalability	Partial	No	No	No	No	Partial
Control traffic	Low	Low	High	High	High	Low for local destinations and high for Inter zone

As we see from Table 3.1, all routing protocols have specific advantages and disadvantages that make them suitable for certain types of scenarios. For QoS requiring applications such as voice/video conferencing, IP telephony, and other time sensitive applications, delay is the main concern for QoS of routing protocols demanding that real time data should be transmitted within a definite time interval. Since proactive routing maintains information that is immediately available, the delay before sending a packet is minimal. On the contrary, reactive protocols must first determine the route, which may result in considerable delay if the information is not available in caches. Moreover, the reactive route search procedure may involve significant control traffic due to global flooding. These reactive routing protocols are less suitable for most time sensitive applications, where QoS support is essential for supporting time critical traffic sessions. Therefore, as per the comparison Table 3.1, to enhance the services of MANETs routing protocol for delivering QoS services in more demanding applications such as video conferencing, voice over IP and multimedia streaming, we are interested to work on OLSR routing protocol.

### **3.5 Summary**

Even though all the works reviewed deal with different aspects of routing in MANETs, there is no work that describes and presents adequate and appropriate QoS routing that integrates all aspects like overhead, delay, throughput, scalability, and transmission error, to have better QoS routing. Therefore, to provide efficient quality of service in mobile ad hoc networks, there is a need to design a new routing technique that will consider multiple constraints.

According to the literature, our solution is intended to use OLSR routing protocols for QoS requiring applications and we will address the following issues which were not covered by the works reviewed.

- Design a better MPR selection approach by considering multiple constraints. In order to provide better services for QoS requiring applications, the proposed algorithm is expected to reduce the possibility of number of collisions, minimize the overlap between MPRs, maximize the global link status of the routing, and minimize the communication delay of the network. In the selection process the link quality will be measured by estimating the number of transmissions and retransmissions needed to send a packet over a link. The

new selection algorithm is expected to consider multiple constraints like delay, quality, number of neighbor coverage and bandwidth constraints.

- Propose a better routing table computation algorithm that will alleviate the problems of the existing ones. In route computation, multiple constraints like distance, link status, etc, will be considered when multiple next hops are existed for a particular destination node. The route entries in the routing table will consist of next hop address, destination hop address, and hop-count.
- Design a lower maintenance clustering algorithm for grouping MANET nodes. Differ from the existing clustering algorithm; our approach is in charging of only grouping of nodes without creating hierarchical communication.
- Mechanisms for efficiently forwarding packets to its destinations will also design.

## **Chapter Four: Design of the Proposed Solution**

### **4.1 Overview**

As described in Chapter 3, the current MANET routing techniques are not efficient enough for QoS demanding applications. Hence, mechanisms for improving the services of MANET applications, in particular when we consider multimedia traffic are needed to be designed. In this thesis, we propose to design a cluster topology and deploy an OLSR protocol for optimal route computation of a network. Dynamic heuristic algorithms for improving the services of OLSR protocol are also designed in the work. The algorithms focus on selection of MPRs, routing table computation and finding of optimal routing path in packet forwarding on a clustered MANET topology.

Following this overview, in the following sections we describe the details about the techniques and the model developed for the proposed solution. In Section 4.2, we describe and present our proposed system architecture for QoS routing in MANET nodes. In Section 4.3, we describe modules which are used for the successful communication of two nodes. Summary about the chapter is described in Section 4.4.

### **4.2 Architectures of the Proposed Solution**

In this Section, we describe and present the overall architecture of our proposed system in a MANET node. In Section 4.2.1, approaches and objectives of clustering MANET nodes are discussed. In Section 4.2.2, we describe and present our proposed QoS aware routing model, algorithms for MPR selection, routing table computations, and optimal routing path computation for forwarding a particular packet to the destination node.

Figure 4.1 shows ad-hoc nodes having different modules on each layer of the network. The modules are organized in a manner for controlling the flow of data within the network. If one packet needs to be routed from node 1 to node n, it should pass through all the layers of the network modules. In the layers there is a service of addressing, error checking, routing, etc., for the successful communication between source node 1 and destination node n.

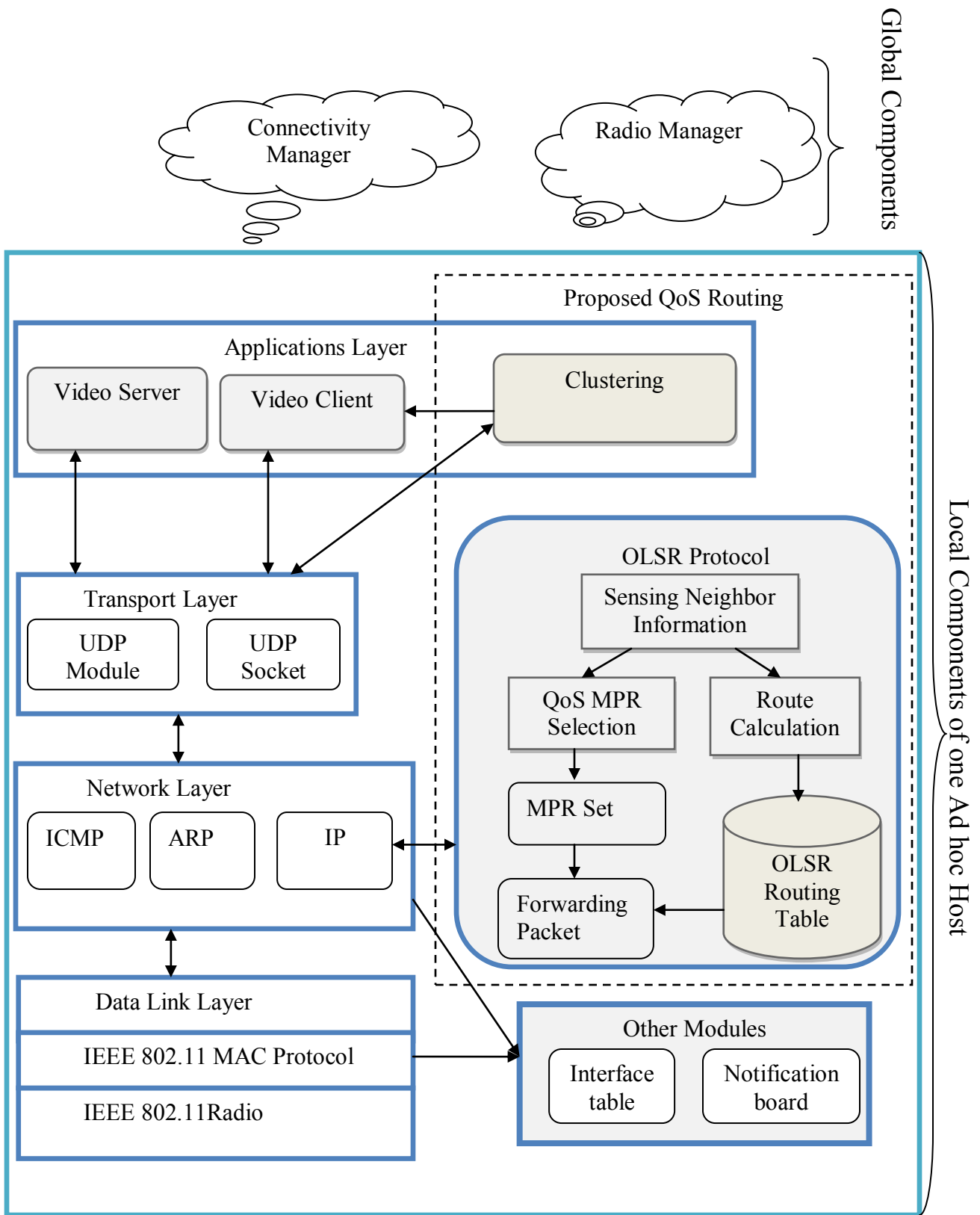


Figure 4.1: Proposed Architecture in MANET Layer

Figure 4.1 depicts the overall MANET protocol architecture that will be implemented in our proposed system. Each ad hoc host contains different modules that will be used for routing a particular packet from the source to the destination host. Initially each node performs clustering operation in order to be one of the cluster states, and routing information of every node is maintained according to the cluster information. To have clustering information in such kind of network helps us to improve routing at the network layer by reducing the size of the routing information, to decrease transmission overhead by updating the status of the environment after topological changes occur, to save communication bandwidth in ad hoc networks by minimizing the broadcast and multicast domain, and to aggregate topology information as the nodes of a cluster are smaller when compared to the nodes of the entire network [38, 39, 40, 45]. Here each node stores only a fraction of the total network information [41, 42]. When the source node runs the applications that are needed to be forwarded to the destination node, first it maintains the routing information based on the information gathered by the clustering algorithm. Our proposed work is mainly focused on the network layer, particularly improving QoS support in OLSR MANET routing protocols. MANET applications which require QoS metrics are implemented based on OLSR protocols for optimal routing computation and relying of the data. Here we have defined two levels of components that would be used in our proposed system:

- **Global Components:** allow to have global knowledge about the whole network. The first one is the connectivity manager which determines, for each node of the network, the nodes in its transmission range. The other one is the radio channel manager in charge of determining the status of the channel whether it is on or off.
- **Local Components:** These are the protocol entities, applications and different modules within the network node that will be used in the proposed system. Data from each of these applications is packaged, transported, addressed, and finally delivered to the appropriate destination node. So in the process, once the application layer prepares the packets that will be routed to the destination, the transport layer accepts it and makes segmentation, error recovery, and retransmission of damaged packet. Then addressing and routing a packet to the destination host will be performed after the packet is delivered to the network layer of the model. Finally, the data link layer provides a means for exchanging data over a common local media. It allows the upper layers to access the

media using techniques such as framing and controls how data is placed onto the media and is received from the media using techniques such as media access control and error detection.

Multimedia data contain images, video, audio and text and each requires its own metrics. In MANET because of its nature of mobility and resource scarcity, routing multimedia data is very challenging, because multimedia data communication needs to grant QoS constraints like bandwidth, delay, and jitter, and routing information are needed to be available at all times.

Here in our proposed system, the video server in the application layer is responsible for offering video streams to every client as per their request. When a client node wants a video data, it initiates a request to the server node. Routing information for passing videos is maintained early and the packets are needed to pass all the layers of the model. To reduce communication overhead, video streaming modules are implemented over UDP and reliable delivery is handled by having the modules resend requests if responses haven't arrived within a specified timeouts period.

#### **4.2.1 Clustering**

In our proposed work, we are interested to design a clustering algorithm for clustering of MANET nodes. Nodes are divided into clusters and the cluster algorithm is performed when a node joins the network. The cluster is performed based on connectivity and ID of nodes within the transmission range, and each node can be in one of the three states which are cluster head, ordinary or gateway. On each cluster zone we have only one cluster head that will monitor the communication between nodes mainly outside the cluster zone. Nodes which are selected as gateway nodes know more than one cluster head, and they allow passing a communication to each neighbor cluster head. The main objective of creating clusters on a MANET is, by limiting the network view of each node, we can reduce the routing complexity and overhead of broadcasting messages. Moreover, the local movement of nodes is handled only within the cluster zone without affecting other parts of the network and so the delay and packet loss is highly reduced. However, initially each node initiates the joining operation by setting a timer and broadcasts a Hello message. This, as a standard MANET topology, may have network overhead.

Thus to manage the topology of a network a number of clustering algorithms are developed by several researchers. The approaches consider different constraints in a different MANET application. Here, we chose to select and customize one of the clustering algorithms as per the following survey [39].

- a. Lin's Scheme:** it is a neighboring based clustering scheme. Every mobile node becomes a member of one of the cluster states based on their node ID. According to a survey done in [39], Lin's scheme has minimal communication in cluster formation and cluster maintenance. Of course, only considering node ID for cluster formation has a drawback in case of mobility, transmission range, and other issues.
- b. Adaptive Multi-hop Clustering Scheme:** maintains a multi-hop cluster structure based on load balancing clustering. This clustering scheme does not describe how the clusters are initially constructed. However, for cluster maintenance each mobile node periodically broadcasts its information; include its ID, CID and status to others within the same cluster. By such message exchange, each mobile node obtains the topology information of its cluster.
- c. Passive Clustering Scheme:** it is an on demand protocol. It constructs and maintains the cluster architecture only when there are ongoing data packets that piggy back "cluster-related information" such as the state of a node in a cluster and an IP address of a node. Each node collects neighbor information through promiscuous packet receptions. Thus, passive clustering does not necessitate background overhead of clustering. Each node participates in clustering by overhearing messages from neighbor nodes and piggybacking own cluster information to outgoing packets.
- d. Distributed Dynamic Clustering Scheme:** it is a probabilistic way of clustering scheme. Its objective is to partition the network into  $(\alpha, t)$  clusters, and maintains  $(\alpha, t)$  clusters asynchronously in a distributed fashion. " $\alpha$ " is a probability that a given cluster path will remain available for a time " $t$ ". As such, the algorithm runs continuously and asynchronously on each active node in the ad hoc network. There is no need for centralized control or periodic re-clustering. Choosing the best cluster head is based on calculating the best probability to reach the cluster head quickly, using  $(\alpha, t)$  criteria.

To maintain a cluster topology, as our objective of providing efficient route for an application which requires QoS support like multimedia data, a lower delay cluster formulation is selected. From the schemes, Lin's scheme, which is a neighbor based clustering, satisfies our criteria and it is selected, and we have made some modification to fully satisfy our requirement. In the existing Lin's cluster formulation, every mobile node keeps its own ID, nodes periodically broadcast their ID to their direct neighbors. Then, each node compares the IDs of its neighbors with its own ID. A node decides to become a cluster head if it has the lowest ID among its neighbors IDs. However, in this algorithm some drawbacks like a highly mobile node with the lowest ID among its neighbors can be selected as a cluster head causing inconvenient re-clustering and undesired cluster head changes in the network. Moreover, using only a lower ID criterion may generate more clusters. So to address this problem, we are considering node connectivity constraint of a node. Based on these constraints, each MANET node decides its state and to be a member of the cluster zone.

Basically, in this work our main concern is maintaining an optimal routing path of each destination node. For instance, if a source node wants to send a packet out of the cluster zone but has no active route which can be used, it floods route request to its cluster head, and then the cluster head receives a request and broadcasts to all neighbor cluster heads. Then every cluster checks whether the destination node is a member to its cluster zone, if not, the request will be discarded. Otherwise, the cluster head that has the address of the destination node will send a reply to the source node cluster head. So based on the reply address and optimal routing path the packet will be forwarded. But, if the destination node is in its cluster zone, the packet can be forwarded directly. Algorithm 4.1 shows the pseudo code of creating a cluster topology for a MANET having  $n$  nodes.

**Input:** Node  $n$

**Process:**

1. Node  $n1$  broadcast hello message to all neighborhood
2. IF (Node  $n1$  connectivity > neighborhood nodes && willingness != will never)
3.       declare itself as cluster head
4. ELSEIF (node  $n1$  node connectivity == node  $n$ )
5.       Compare node ID
6.       IF (Node  $n1$  ID < node  $n$  ID)
7.       declare itself as cluster head
8.       ELSE
9.       declare itself as ordinary node
10. ELSEIF (Node  $n1$  is neighbor of two or more cluster heads )
11.       declares itself as gateway node
12. ENDIF

**Output:** Cluster heads, Gateway, and Ordinary nodes of MANET

*Algorithm 4.1: Modified Lin's Clustering Algorithm*

At line 1 of the algorithm 4.1, a node starts a flooding process in which a clustering request is sent to 1-hop neighbors. Then, each node in the network maintains its node ID with respect to its neighbor node connectivity. Based on conditions as specified in algorithm 4.1, line 2 up to 7, a node is selected as a cluster head if it has the highest connectivity in the neighbor. In case of equal connectivity, a node has cluster head priority if it has lower ID. Although each node only determines one cluster, clusters may overlap. This means that a node can belong to all clusters whose cluster head is at most  $h$ -hops distance from the node. Nodes that belong to more than one cluster become gateway nodes.

As the node is mobile, its transmission range may vary from time to time. So nodes beyond its transmission range can shift from one cluster zone to another. At this time, cluster heads with lowest node connectivity and high in node ID may give up its role to the one having a better node connectivity and node ID of another node.

### 4.2.2 OLSR Protocol

As we discussed in the Literature Review Section, OLSR is one of the most known proactive routing protocols where nodes maintain the route information in a routing table, so a route is available immediately when it is required. Figure 4.2 shows the proposed model for QoS routing using OLSR. It contains services such as sensing neighbors' information, QoS MPR selection, and routing path calculation and finally the collected information about the route is stored in the routing table of the protocol.

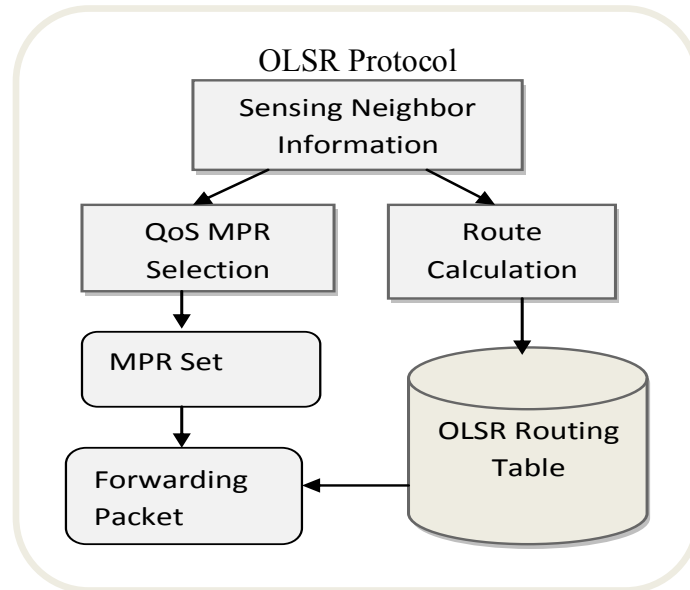


Figure 4.2: Proposed QoS Routing Model

#### 4.2.2.1 Sensing Neighbors' Information

Each node periodically broadcasts a HELLO message, and senses its current neighbors within its transmission range. For a particular node, any other node that is within its radio transmission range is called a neighbor. All nodes consist of neighbor set which holds details of its neighbor nodes. Since all nodes might be moving, the neighbors for a particular mobile node are always changing. The neighbor set is dynamic and needs to be updated frequently.

#### 4.2.2.2 QoS MPR Selection

In OLSR [1, 6, 15], each node of the network independently selects its own set of MPRs. The MPR set is calculated in a manner to contain a subset of one hop neighbors which covers all the two hop neighbors, i.e., the union of the neighbor sets of all MPRs containing the entire two hop neighbor set. In our work, selections of MPRs are limited to the cluster zone. This will help us to

minimize the occurrence of overlapping between nodes. The MPR set is re-calculated when a change in one hop or two hop neighbor sets with bi-directional link is detected or a change in their QoS condition is detected. In order to build the list of the two hop nodes from a given node, it needs to track the list of bi-directional link nodes found in the Hello messages received by this node. Then the received two hop neighbor information is stored in the neighbor table.

In Chapter 2, different MPR selection schemes have been discussed and a number of factors have major impacts on the selection process. From the literature, we can conclude that, selecting MPRs with QoS constraints is more appropriate for applications in which QoS support is crucial. However, existing works with QoS constraints have problems of overhead, delay, packet loss and others in the selection of an optimal quality link. In this work, in the MPR selection, links with high bandwidth and low delay will not be omitted. The MPR set will be calculated by a node in such a way that it, through the neighbors in the MPR set, can reach all 2-hop neighbors considering set of criteria applied not just to the 1-hop neighbors but also to the 2-hop neighbors of a given node. The criteria that we are going to implement in MPR selection are node connectivity, delay, quality (in terms of link status and number of transmissions), and bandwidth. Considering multiple constraints in MPR selection process minimizes the number of MPR nodes for a particular node. This means the possibility of overlapping of nodes is minimized.

### **Description of QoS Metrics**

**a. Node connectivity:** Every node must detect the neighbor nodes with which it has a direct and bi-directional link. For this, each node periodically broadcasts its Hello messages, containing the list of neighbors known to the node and their link status. The Hello messages that are received by all one hop neighbors are not forwarded. So based on this message each node knows its number of neighbor nodes which are directly connected to it.

**b. Delay:** It is the time taken between two nodes for which a source node  $n_1$  sends a message to a destination node  $n_2$  and successfully delivered. Each node includes in the Hello message the creation time of this message. When a neighbour node receives this message, it calculates the difference between sent time and the current time; this is done in a synchronized network. This metric is important in delay sensitive applications such as video and voice transmission. In EQ. 4.1 we have shown our formula for calculating a delay of nodes.

$$Delay = \frac{\sum_{0 \rightarrow n} (Received\ time - Sent\ time)}{n} \dots\dots\dots (EQ. 4.1)$$

\* n is the total packet received

**c. Quality:** It represents the capacity of the link between two nodes n1 and n2. Quality of a link is computed based on periodical exchanges of the Hello messages between each node and its neighbors in a certain time interval. The links must be checked in both directions in order to be considered valid. In EQ. 4.2 we have shown our formula for calculating the link quality between node n and its 1-hop neighbors:

$$Quality = \frac{Hello\ message\ n\ received\ from\ 1-hop\ neighbors}{Total\ Hello\ message\ 1-hop\ neighbors\ has\ sent} \dots\dots\dots (EQ. 4.2)$$

Bigger quality indicates that a better communication exists among 1-hop neighbors. Thus, results in a higher packet delivery ratio.

**d. Link state:** shows the status of the link at a given time T. Here T is referred to as the estimation period (namely, the time needed for estimating available bandwidth). In EQ. 4.3 we have shown our formula for calculating the status of a links. The state (s) of a given link i at time t is as follows:

$$S_i(t) = \frac{Total\ available\ bandwidth - Transmitted\ data\ size}{Total\ available\ bandwidth} \dots\dots\dots (EQ. 4.3)$$

$$S_i(t) = \begin{cases} 0\ or\ less\ than\ 0, & link\ is\ busy, \\ Greater\ than\ 0, & link\ is\ idle\ or\ there\ is\ unused\ bandwidth \end{cases}$$

In [6, 10], to compute the available link bandwidth of two nodes it uses idle time. As shown in EQ.4.3, link state is calculated by subtracting the transmitted data size from the total available bandwidth and dividing it by the available bandwidth. The available link bandwidth between two nodes n1 and n2 is equal to the maximum of their idle time multiplied by the maximum bandwidth. Therefore, based on the above values, QoS metrics is computed as in EQ.4.4:

$$QoS\ metrics = (Quality + available\ link\ bandwidth) - Delay \dots\dots\dots (EQ. 4.4)$$

Algorithm 4.2 shows the proposed algorithm in the selection of MPRs of a MANET with  $n$  nodes, 1 hop neighbor set  $N_1(n)$ , and 2 hop neighbors set  $N_2(n)$ . Each node  $n$  maintains the set of its MPR selectors. This set contains the nodes that have been selected by  $n$  as a MPR. Node  $n$  of MPRs is only in charge of forwarding broadcast messages received from one of its  $N_1(n)$ .

**Input:** Node  $n$ ,  $N_1(n)$ ,  $N_2(n)$

**Process:**

1. Start with an empty multipoint relay set  $MPR_n$ ;
2. Find and calculate the number of  $N_1(n)$  of the current node
3. IF ( $N_1(n)$  status == symmetric && willingness != will never )
4. Add these  $N_1(n)$  nodes to the multipoint relay set  $MPR_n$
5. Select  $N_1(n)$  as MPR which provides the only path to reach some nodes in  $N_2(n)$
6. Remove the nodes from  $N_2(n)$  which are covered by a node in  $MPR_n$
7. **While** ( $N_2(n)$  not empty) **Do** //all nodes in  $N_2(n)$  that are not covered by the  $MPR_n$
8.     IF ( $N_1(n)$  is not in  $MPR_n$ )
9.         Calculate the number of nodes that are reachable through it among the nodes in  $N_2(n)$  and which are not yet covered by  $MPR_n$
10.         Calculate the QoS metrics value //as shown in EQ.4.4
11.         Select node of  $N_1(n)$  as a MPR which reaches the maximum number of uncovered nodes in  $N_2(n)$  and meets the QoS requirements
12.     ENDIF
13.     ELSE
14.         IF (multiple choices of  $N_1(n)$  ) //  $N_1(n)$  nodes having the same number of Node connectivity
15.         Select node of  $N_1(n)$  as a MPR which have a maximum QoS metrics
16.     ENDIF
17.     Remove the nodes from  $N_2(n)$  which are covered by a node in  $MPR_n$

**Output:** MPR set of  $n$

*Algorithm 4.2: Algorithm for MPR Selection*

The first five steps (lines 1 through 5 of Algorithm 4.2) are almost the same as those described in the previous section. Initially, each MANET node broadcasts a Hello message to all its neighbor nodes, and collects information about its neighbor status. Nodes which are selected as MPR from

1-hop neighbors should have a status of symmetric (nodes can hear each other) and willingness (the ability of a node to carry and forward the incoming packet) differ from 0. Every 1-hop neighbor which can be selected as MPR is expected to satisfy the required QoS constraints. So based on the incoming status, a node selects its MPR node among 1-hop neighbors, which are reachable to all other neighbors. While there exist nodes in 2-hop neighbors which are not covered by the selected MPR nodes (line7 through 16 of Algorithm 4.2), the node checks the node connectivity of 1-hop neighbors and selects node of 1-hop neighbor as MPR which reaches the maximum number of uncovered nodes in 2-hop neighbors. However, when there are more than one 1-hop neighbors covering the same number of uncovered 2-hop neighbors, it selects the one having a maximum QoS metrics to the current node.

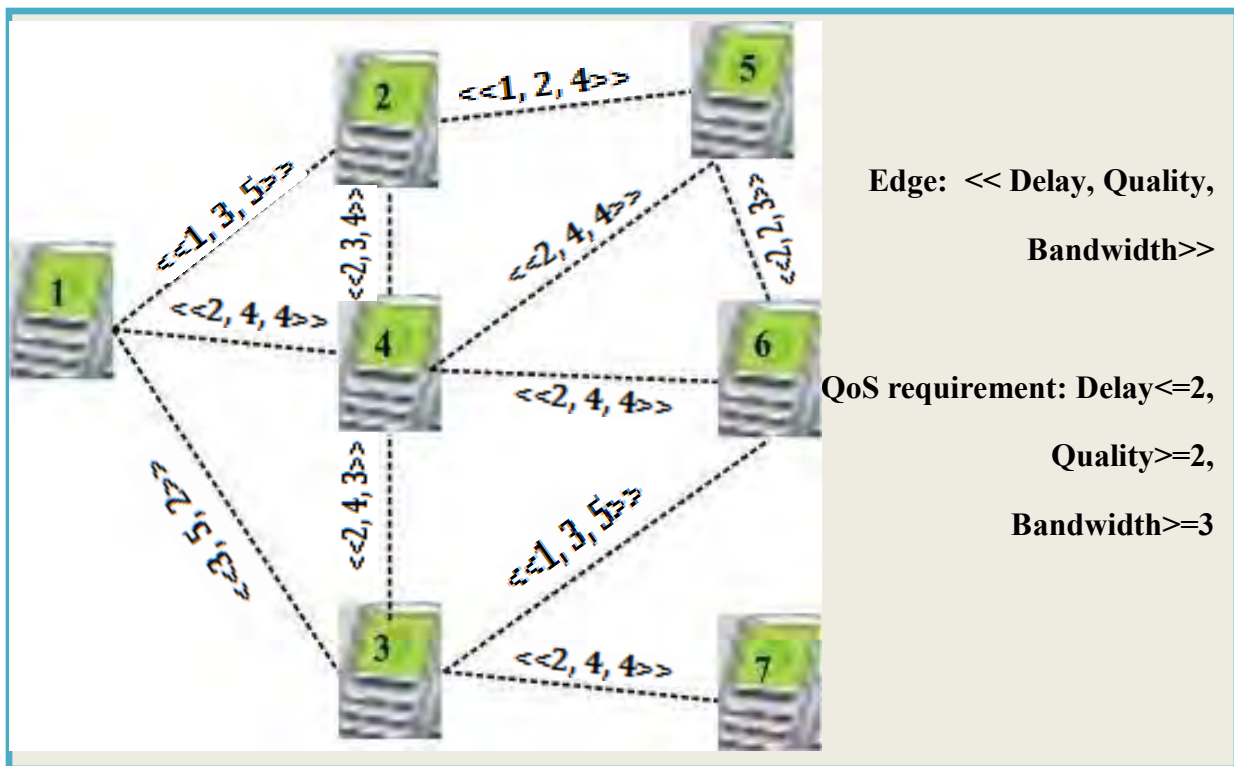


Figure 4.3: MANET Nodes

Table 4.1: MPR Node Selection

Node	1 Hop Neighbors	2 Hop Neighbors	MPR
3	1 4 6 7	2 5	4

As we see in Figure 4.3, based on Algorithm 4.2, node 3 has chosen MPR node among its neighbor nodes (1, 4, 6, 7). First it broadcasts a hello message to all its neighbors, and then each neighbor who is receiving the packet will broadcast it to its equivalent neighbor nodes. The process continues and finally, node 3 will receive several packets from its one hop neighbors (1, 4, 6, 7). The MPR set is calculated from the reply of one hop neighbors (1, 4, 6, 7) which cover all the two hop neighbors (2, 5), i.e., the union of the neighbor sets of all MPRs containing the entire two hop neighbor set. Once node 3 knows the status of its one and two hop neighbors, based on constraints a comparison between one hop neighbors (1, 4, 6, 7) is performed. From the neighbors only node 4 has a neighbor of node (2, 5), so this node is the only node that has the maximum node connectivity among all other nodes and reachable to the 2-hop neighbors of node 3. So as we see in Table 4.1, among one hop neighbors of node 3, node 4 is prioritized as MPR node of node 3. In addition to high node connectivity the link between nodes 3 and 4 satisfies QoS constraints they are expected to have. MPR selection process is the same for other nodes (1, 2, 4, 5, 6, 7).

#### **4.2.2.3 MPR Set**

MPR set is a list of MPRs which are selected for relying of routing packet. When a source node wants to send packets to the destination node it select the MPR from its MPR set. Through this node the source node can cover all nodes that are 2-hops away.

#### **4.2.2.4 Route Calculation**

To transmit a multimedia data in the network each node calculates a better optimal routing path to the destination of every other node. The calculation is focused by considering QoS constraints for reliable delivery of data. Once the route information to the destination node  $n$  is computed, it will be stored in the routing table of the source node. The details about route computation and recording of results are discussed in the next Section.

#### **4.2.2.5 OLSR Routing Table**

Every mobile node in the network maintains a routing table in which all the possible destinations within the network and the number of hops to each destination are recorded. These routing tables are broadcasted to current neighbors periodically. Maintaining routing table information is performed inside and outside the cluster zone of the destination node. In the process, cluster

heads have a big role to locate the destination address of a particular node. Once a source node wants to maintain a routing path for destination node  $n$  outside the cluster zone, first it should communicate with its cluster head, and then the cluster head finds a means of communication between two nodes.

In this thesis, the route entries in the routing table will consist of destination address, next hop address, and hop-count. In order to reserve a better routing path that satisfies all possible QoS constraints we have designed an algorithm for computing the routing tables of each node. The entries are recorded in the table for each destination in the network when the route is known. All the destinations for which the route is broken or partially known are not entered in the table. The routing table is re-calculated when a change in the neighbor is detected. Algorithm 4.3 shows the algorithm for computing the routing table.

**Input:** Node  $n$ , 1-hop neighbor set  $N_1(n)$

**Process:**

1. Initially, all old entries are removed from the routing table.
2. The new entries are recorded in the table from the  $N_1(n)$  as the destination nodes and the hop count  $h$  is set to be 1.
3. FOR all route entries in which destination nodes is  $h+2$  hops are recorded
4.     IF(node destination is in the same cluster zone)
5.         IF(node destination == next node and no multiple next node)
6.             Add a new entry with the destination node in the routing table
7.         ELSEIF (multiple next node destination)
8.             Compare the number of hops and their link status like delay and quality to the destination
9.             Select and record the one having a better route destination
10.         ENDIF
11.     ENDIF
12.     ELSE
13.         IF(node destination is in different cluster zone)
14.             It looks cluster heads associate with destination node
15.             Compare routes to the destination //number of hops
16.             Add next node with destination node
17.         ENDIF
18. ENDFOR

*Algorithm 4.3: Algorithm for Route Computation*

Based on clustering information, each node of the network maintains a topology table, in which it records the information about the topology of the network. Routing table computation is based on the information contained in the neighbor and topology tables.

For instance, if we take Figure 4.3, based on Algorithm 4.3, each node maintains its routing table of any destination node. If all destination nodes are found within the same cluster zone (line 3 through 7 of Algorithm 4.3), communication is performed locally. Node 1 in Figure 4.3 calculates its routing table with destination node 5 as follows. First node 1 gathers some connected pairs [next-hop, destination-hop], which will be a pair having a path 1-2-5, 1-4-5, 1-4-6-5, 1-3-6-5, etc. As it is having multiple routing paths to the destination node 5, comparison

between paths is performed based on Algorithm 4.3. For instance, if node 1 wants to find a path 1-2-5 to the destination, it first finds the pair [2, 5], then [1, 2]. Finally, if routing path 1-2-5 is better and optimal than all other routing paths, it will be recorded in the routing table of node 1 as the destination path of node 5. If the destination node is out of the cluster zone, the source node is communicated with its cluster head. Then local cluster head communicates with its neighbor gateway node. This node has the ability of knowing more than one cluster heads. So the gateway node finds and locates the cluster head of the destination node.

#### **4.2.2.6 Forwarding Packet**

Users of ad hoc networks may want to use QoS demanding applications such as Voice over IP, video conferencing, and streaming multimedia when they are connected to the network. So to get the services of such MANET applications, appropriate techniques are needed to be available.

When a packet is sent from source to destination node, a better optimal routing path that satisfies the application's QoS requirements are considered. Therefore, if the destination node is within the transmission range of the source node, i.e., destination node is the neighbor of the source node, then it will communicate directly. But if the destination node is outside the transmission range of the source node, then the source node needs to find the path to the destination via some other intermediate nodes. In our proposed work, nodes which are selected as MPR will forward the packet on an optimal routing path of the destination node. Algorithm 4.4 shows the pseudo code of forwarding packets to its destination address.

**Input:** *Node n*

**Process:**

1. *Know the neighbors and all other nodes of the network* ← *Node n broadcasts hello message*
2. *Create a table of nodes and its corresponding neighbors*
3. *Generate a list of destination nodes*
4. *FOR (Node n that wishes to transmit some data to destination node n)*
5.     *The routing path associated with the source and destination nodes will be searched and selected from the routing table.*
6. *ENDFOR*
7. *Forward packet*

**Output:** *Packets are forwarded to the destination node*

*Algorithm 4.4: Algorithm for Forwarding Packets*

For instance, in Figure 4.3, assume node 3 is the source node and node 5 is the destination. Before a source node broadcast to the destination node, based on Algorithm 4.4, it locates the next node which can forward a packet to the destination node 5 (lines 4 through 6 of Algorithm 4.4). Then, an optimal routing path to the destination will be selected and the packet is forwarded via the selected next node 4.

### 4.3 Other Modules

- **Notification Board:** It allows notifying of node status about events such as routing table changes, interface status changes, interface configuration changes, wireless handovers, changes in the state of the wireless channel, mobile node position changes, etc.
- **Interface Table:** This table allows recording the interface address of MANET nodes.

#### **4.4 Summary**

To route a packet which is either data or multimedia content, the node should cover all layers of the model. For transmitting multimedia applications, the source and the receiver nodes will be able to use UDP, and applications are implemented on top of UDP modules. UDP modules and sockets are responsible for connecting, receiving and forwarding video packets to the layers. Similarly, OLSR module is directly connected to the network layer. When a packet arrives at the IP layer, the layer immediately sends the packet to the routing protocol. Once the packet arrives at the OLSR module, a path that will satisfy a better QoS metrics between the communication end points of a MANET node will be computed and encapsulated in the packet header, and the nodes which are in charge of relaying the casting packet to the destination are also calculated.

## **Chapter Five: Prototype Implementation and Evaluation**

### **5.1 Overview**

Routing multimedia data in a dense flat MANET network is very challenging because, nodes are unorganized and unstructured, and there is high flooding rate of multicasting and broadcasting messages. Hence, to address these challenges, we have designed approaches for improving and providing suitable QoS routing technique for MANET applications as shown in Chapter 4. Applying clustering schemes in such kinds of networks facilitates the performance of a routing protocol by reducing the routing complexity and minimizing of broadcast and multicast range. As per our proposed routing protocol, OLSR provides a strategy that discovers the best route that links up two or more nodes in a network. The strategies take into account variables in network such as the unpredictable topology, the number of links, the bandwidth, etc.

Due to high cost of MANET nodes, we have implemented and evaluated the proposed QoS routing using a simulated MANET environment and nodes. The implementation detail description of this work is presented in various Sections of this Chapter. Section 5.2 describes the development environment employed to implement the system. Section 5.3 presents the implementation description of the various components. Section 5.4 describes the performance of different MR selection algorithms. In Section 5.5, the simulation experiment and evaluation result are described. Finally, we summarize the Chapter in Section 5.6.

### **5.2 Development and Simulation Tools**

The selection of development environment and simulation tools that were used for implementation and evaluation of the proposed solution are described in this Section.

Network simulation is the most useful and common methodology used to evaluate different network topologies without real world implementation [46, 48, 49]. There are a number of network simulators, for instance, NS-2, NS-3, OMNET++, SWAN, OPNET, QUALNET, J-SIM, GLOMOSIM, etc. All these network simulators have varied factors to be considered in simulating a MANET environment. Thus, selecting an appropriate network simulator and assessing which one will provide optimum performance and suitability of network simulator for implementing and evaluating the proposed work is crucial. Here we have summarized surveys on various network simulators as follows:

In [46], authors have described and analyzed wireless network simulators like QUALNET, NS-2, J-SIM, OMNET++ and OPNET. The analyses done for these simulators are on the basis of their features like language supported, platform supported, GUI support, licensing, and animation support. After comparison of these simulators on the basis of their features given above, the authors suggested that NS-2 and OMNET++ should be the best choice when open source network simulators are considered for research work.

In [48], various simulators like NS-2, NS-3, and OMNET++ are evaluated. The authors have analyzed these simulators on the basis of the factors like, impact of simulation runtime on the network size and probability of dropping packets. They have also considered the memory usage as a metrics in order to analyze the memory requirements of various simulators. Large variation in runtime performance as well as in memory usage was found when the simulation results were analyzed.

As we have observed from the surveys [48, 49, 50], NS-2 and OMNET++ are the best choices which provide better performance and simulation environment for MANETs. However, considering criteria like ability to run large networks, availability of varieties of modules, debugging and tracing support, supporting powerful GUI, flexibility and dynamic topology creation, we have selected OMNET++ with INET framework for implementing and evaluating our proposed work.

OMNET++ [46, 47] provides a component based hierarchical, modular and extensible architecture. Components are programmed in C++ which consists of the simulation kernel and utility classes for statistics collection and topology discovery. Modules relationships and communication links are stored as Network Description (NED) files and can be modeled graphically. Alongside the simulation kernel library, the simulation environment contains a Graphical Network Editor (GNED), graphical (Tkenv) and command line interfaces for simulation.

INET is an open source communication networks simulation package for the OMNET++ simulation environment [47]. It contains models for several wired and wireless networking protocols, including UDP, TCP, SCTP, IP, IPv6, Ethernet, PPP, 802.11, MPLS, OSPF, and many others.

### 5.3 Prototype Implementation

In mobile ad hoc networks, the movement of the network nodes may quickly change the topology, resulting in the increase of the overhead of messages in topology maintenance [39]. In proactive protocols like OLSR, sending control messages to all interfaces also generate a very high overhead. Thus, applying clustering schemes in such kinds of networks will minimize this overhead. Taking into account node connectivity of Algorithm 4.1, helps for maintaining clustering information with lower communication delay and overhead, and minimize the possibility of re-clustering MANET nodes.

Figure 5.1 shows the simulation of 25 mobile hosts using OMNET++ and the circles are the transmission ranges of each host. If hosts are nearby or in transmission range, they can directly communicate and transmit packets to each other. Otherwise, as the distance increases between hosts, the intermediate hosts are in charge of establishing a communication between nodes. Nodes are highly mobile; they move randomly in different directions and they have limited resources like memory, CPU, bandwidth, battery, etc. Therefore, to establish a stable communication channel between these nodes, the selected intermediate nodes are expected to have better resources.

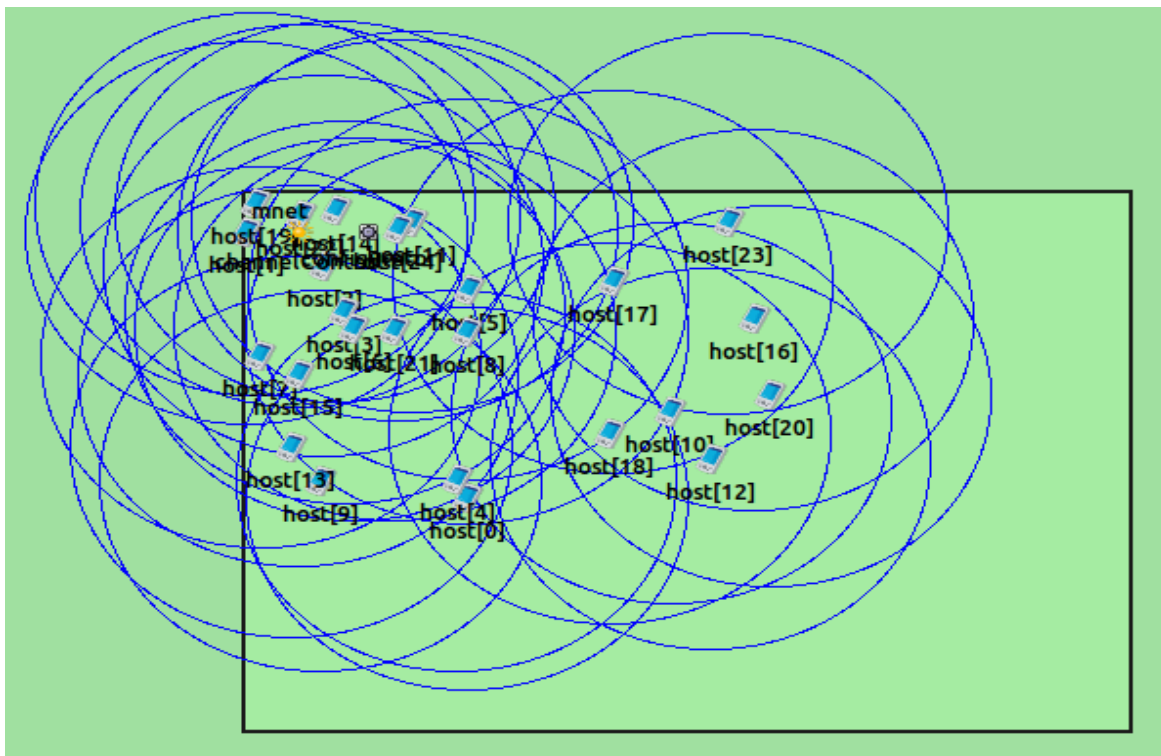


Figure 5.1: MANET Setup

Each MANET host of Figure 5.1 contains different encapsulated modules that will be used for routing a particular packet from the source to the destination host. As we see in Figure 5.2, on the top layer, there are modules like video server, video client and clustering. At the middle layer, transporting and routing maintenance modules like IP and MANET routing protocols are found. On the bottom layer, there are channel modules which contain the networking interfaces of the node. Wlan0 module is a wireless network interface that receives and sends data frames. Lo0 module is a loop back interface that responds to the address 127.0.0.1. Other modules which are found in MANET hosts are interface table, routing table, notification board, and mobility. Through mobility module each node in the network is becoming movable. Signal strengths, radio interference and channel occupancy depends on the distances between nodes. Mobility module influences the results of the simulation like data packet delivery ratio, end to end delay and average hop count.

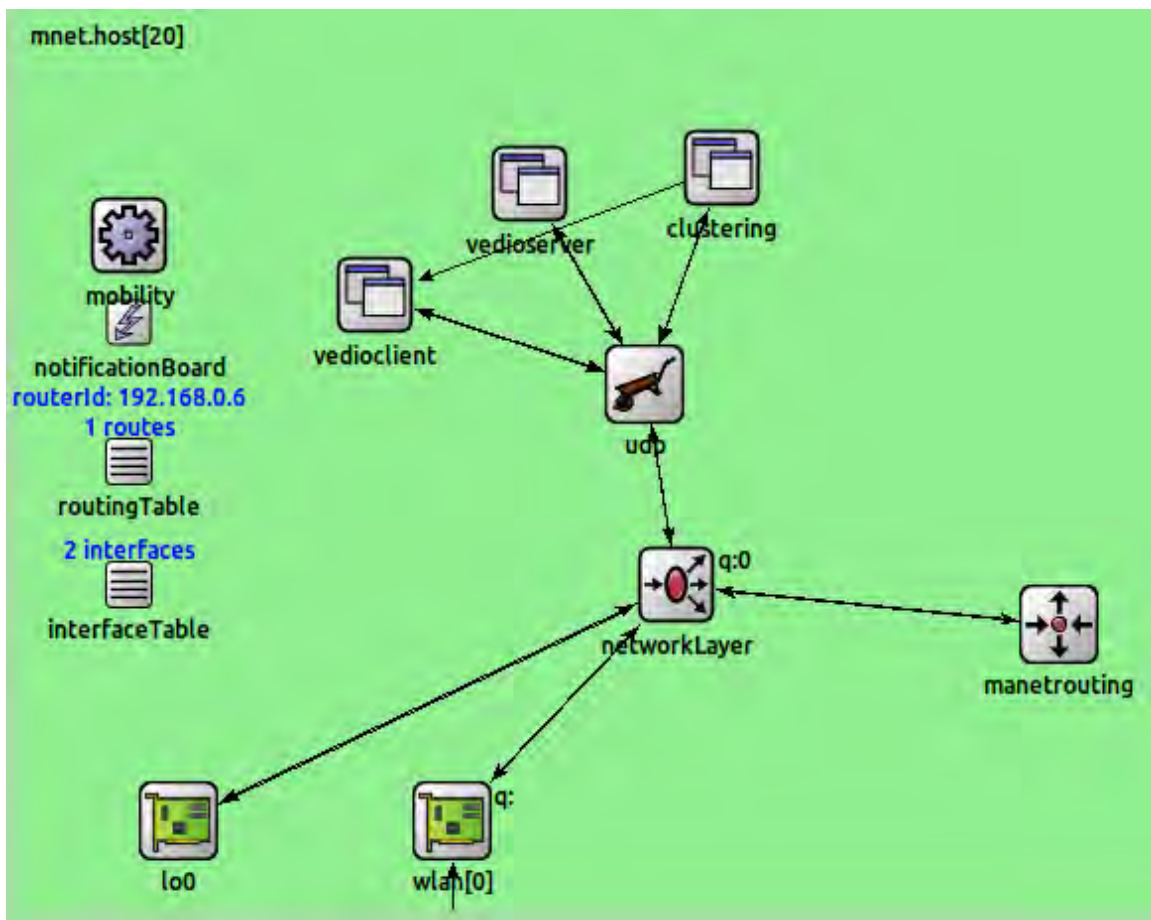


Figure 5.2: Connection of Modules in one MANET Host

As we defined the setups in Appendix A, Figure 5.2 shows the relationship between the MANET routing modules. These modules reside in every mobile node of a network. Initially, each mobile node adjusts its own network setting like interface, IP address, etc. When the simulation begins, every node broadcasts a cluster solicitation message to its neighbors. It waits for a timeout of  $t$  and if it receives a reply message within that period, based on Algorithm 4.1 it examines the hop ID and connectivities of the neighbors. If the hop is less than or equal to the neighbor, then the node sends a cluster acceptance message to all the nodes from which replies have been received, and make clustering decision. If this condition fails, the node declares itself as the cluster head. If the node does not declare itself as a cluster head and receives more than one reply to its cluster solicitation message, then the node declares itself as gateway and informs all the nodes from which it received replies. This is because multiple replies to its cluster solicitation message imply that the node is within the transmission range of multiple clusters. Once the clustering is completed, every node is aware of its neighbors and the communication time, broadcasting and multicasting range is minimized for maintaining routing information.

After clustering formulation is completed, maintaining and discovering of routing information is performed using MANET routing protocol. Initially, the protocol erases all previous entries of the routing information, and then the network layer (IP) transfers any generated packet to this routing protocol, then the protocol particularly OLSR, floods the network with link state information messages to find an ad hoc path to the destination node of the packets.

As we discussed in the previous Chapters, the link state information is constructed by every node and involves periodically sending hello and TC messages. This information is used to determine the best path to every destination in the network. Due to the proactive nature, the routes are immediately available when needed. The protocol is based on hop by hop routing, i.e., each routing table lists, for each reachable destination, the address of the next node along the path to that destination.

To construct a topology map, periodically every node implements topology discovery mechanisms like link sensing, neighbor detection and topology sensing using the information generated by the clustering algorithm. In the first phase, every node populates its local link information base (link set) and establishes communication with its symmetric neighbors, i.e., nodes with bidirectional communication. During the neighbor detection phase, every node

populates its neighborhood information base (i.e., 1-hop and 2-hop neighbor set). The link sensing and neighbor detection phases are based on the periodic exchange of Hello messages. Hello messages are solely transmitted to 1-hop neighbors. In every Hello message, the nodes report their 1-hop neighbors. This information allows every node to construct and maintain neighbor table, as well as to select its MPR set. In the neighbor table, each node records the information about the 1- hop neighbor link status (i.e., unidirectional, bidirectional or MPR). With this information every node builds its MPR set, i.e, the neighbors that selected that node as their MPR. From simulation setup of Figure 5.1, Table 5.1 shows set of MPR nodes with their respective selector set.

*Table 5.1: Set of MPRs and MPR Selector*

<b>MPRs</b>	<b>Selector Set</b>
Host [0]	Host [23], Host [21], Host [20], Host [18], Host [17], Host [16], Host [15], Host [10], Host [5], Host [1], Host [3]
Host [3]	Host [19], Host [11], Host [6]
Host [8]	Host [20], Host [17], Host [0], Host [4], Host [2]
Host [9]	Host [21], Host [19], Host [15], Host [14]
Host [13]	Host [2], Host [24], Host [14], Host [11], Host [8], Host [7], Host [22]
Host [15]	Host [2], Host [13], Host [24], Host [18], Host [14], Host [8], Host [7], Host [5], Host [22]
Host [19]	Host [11], Host [7], Host [4]
Host [21]	Host [12], Host [20], Host [16]

As shown in Table 5.1, only nodes which are selected as MPR participate for relying control packets to other nodes in the network.

Topology sensing is achieved through the exchange of TC messages within a specified range. These messages allow each node to construct its topology table and to declare its MPR selector set. A TC message contains the MPR selector set of its originator. A node that has an empty MPR selector set does not send or retransmit any TC messages. An MPR forwards a message only if it comes from a node in its MPR selector set (i.e., a source-dependant mechanism).

Finally, routing tables are constructed using information from the 1-hop and 2-hop neighbors and the topology table. Every node executes Algorithm 4.3 to obtain the shortest path to every other node more than two hops away. Routing tables include the next node and number of hops to reach every other node in the network. As we are using hop by hop routing method, the source node stores in its routing table only the next hop to reach node n. Figure 5.3 shows routing table of one MANET host.

```

****OLSR Routing Table****
dest node:192.168.0.1  next node:192.168.0.6  iface:192.168.0.16  hop count:2
dest node:192.168.0.2  next node:192.168.0.21  iface:192.168.0.16  hop count:2
dest node:192.168.0.3  next node:192.168.0.3  iface:192.168.0.16  hop count:1
dest node:192.168.0.4  next node:192.168.0.21  iface:192.168.0.16  hop count:2
dest node:192.168.0.5  next node:192.168.0.14  iface:192.168.0.16  hop count:2
dest node:192.168.0.6  next node:192.168.0.6  iface:192.168.0.16  hop count:1
dest node:192.168.0.7  next node:192.168.0.21  iface:192.168.0.16  hop count:2
dest node:192.168.0.8  next node:192.168.0.14  iface:192.168.0.16  hop count:2
dest node:192.168.0.9  next node:192.168.0.6  iface:192.168.0.16  hop count:2
dest node:192.168.0.10  next node:192.168.0.6  iface:192.168.0.16  hop count:2
dest node:192.168.0.11  next node:192.168.0.21  iface:192.168.0.16  hop count:2
dest node:192.168.0.12  next node:192.168.0.21  iface:192.168.0.16  hop count:2
dest node:192.168.0.13  next node:192.168.0.21  iface:192.168.0.16  hop count:4
dest node:192.168.0.14  next node:192.168.0.14  iface:192.168.0.16  hop count:1
dest node:192.168.0.15  next node:192.168.0.21  iface:192.168.0.16  hop count:2
dest node:192.168.0.17  next node:192.168.0.21  iface:192.168.0.16  hop count:4
dest node:192.168.0.18  next node:192.168.0.14  iface:192.168.0.16  hop count:2
dest node:192.168.0.19  next node:192.168.0.21  iface:192.168.0.16  hop count:2
dest node:192.168.0.20  next node:192.168.0.21  iface:192.168.0.16  hop count:2
dest node:192.168.0.21  next node:192.168.0.21  iface:192.168.0.16  hop count:1
dest node:192.168.0.22  next node:192.168.0.21  iface:192.168.0.16  hop count:5
dest node:192.168.0.23  next node:192.168.0.21  iface:192.168.0.16  hop count:2
dest node:192.168.0.24  next node:192.168.0.21  iface:192.168.0.16  hop count:5
dest node:192.168.0.25  next node:192.168.0.21  iface:192.168.0.16  hop count:2

```

*Figure 5.3: Sample Routing Table Snapshot*

After all routing information is maintained in the routing table, the clustering module notifies the client nodes about the readiness of the routing information. Then, when the client node wants to get a video from server nodes, it initiates a video request to this node. As per the request of the client node, the server node provides video to the client node. Figure 5.4 shows how a client node requests and receives a video stream.

In Figure 5.4, client host-7 (192.168.0.8:41960), has sent video streaming requests to server host-2 (192.168.0.3:41961). Client host is found 2-hop away from the server host, since 20 byte of

video packet is transmitted through neighbor node of 192.168.0.1:41960, and delivered to the client node.

```
** Event #96628 T=60 mnet.host[7].vedioclient (UDPVideoStreamCli, id=175), on selfmsg 'UDPVideoStreamStart' (cMessage, id=94)
Requesting video stream from 192.168.0.3:41961
sending stream127.0.0.1
sending stream192.168.0.4
sending stream192.168.0.1
sending stream192.168.0.6
sending stream192.168.0.5
sending stream192.168.0.10
sending stream192.168.0.8
** Event #98890 T=60.024056065298 mnet.host[7].vedioclient (UDPVideoStreamCli, id=175), on 'VideoStrmPk' (cPacket, id=80982)
Receive video stream packet: (cPacket)VideoStrmPk (20 bytes) 192.168.0.3:41961 --> 192.168.0.8:41960
TTL=30 hopcount=2 next node:192.168.0.1
```

*Figure 5.4: Sample Video Streaming Snapshot*

## 5.4 Analysis of MPR Selection Algorithms

### 5.4.1 Description of MPR Selection Algorithms

As we describe in the previous Chapters, to improve the service of OLSR, different schemes for the selection of MPR nodes are designed in the last decade. The decision of how each node selects its MPRs aims in finding the best 1-hop neighbors which provide maximum data rate and minimum delay to each 2-hop neighbors. So the ability of considering multiple appropriate constraints in the selection of MPR nodes has impact for providing QoS routing. The initial phase of all MPR selection procedures is almost the same. However, when there are more than one 1-hop neighbors covering the same number of uncovered 2-hop neighbors, different schemes used different criteria to give a priority for a node which can be selected as MPR. As we design an algorithm for multimedia packet routing, the selected MPR selection algorithms should satisfy QoS requirement. Here in Table 5.2, we have summarized the most popular QoS based schemes and compared with our proposed approach. Although these works have been reviewed in Chapter 3, the table is intended to summaries them since our work is based on these works.

*Table 5.2: Summary of MPR Selection Algorithms*

<b>Approach</b>	<b>Summary</b>
QoS MPR Selection-1 [4,14,6,35]	This algorithm changes procedure in order to provide QoS priorities. In case of multiple 1-hop neighbors it selects a node with high node connectivity to the 2- hop neighbors. If equal solution still exists, a node with maximum bandwidth is chosen as MPR. Then, likely MPRs with large bandwidth are selected, but the improvement is insignificant.
QoS MPR Selection-2 [6,16,35]	It is similar to the first one but selects nodes with higher bandwidth as MPRs, and the delay is used when there is a tie. The idea behind QoS MPR selection-2 is to select the best bandwidth neighbors as MPRs until all the 2-hop neighbors are covered. In this scheme, neighbors that guarantee maximum bandwidth and minimum delay among two-hop neighbors have the probability to be selected as MPRs.
QoS MPR Selection-3 [6, 35]	The idea of this algorithm is to let all 2-hop nodes have an optimal bandwidth path through MPRs to the source node. Here, the optimal bandwidth path is the path with the highest bottleneck bandwidth. For each 2-hop neighbor of source node, select as MPR a one-hop neighbor of source node that covers this two hop neighbor if it has the largest bottleneck bandwidth path to source node. Each 2-hop node has to go through this process until is finds an optimal path to the source node.
Proposed QoS MPR Selection	This is our proposed algorithm; we describe a new heuristic for selecting the optimal MPR set. An optimal MPR set for a node is defined as a subset of the 1-hop neighbors, which covers the 2-hop neighbors of that node, and it has the minimum number of nodes among all other sets that cover the two-hop neighbors of the node. In this algorithm, first it checks 1-hop node connectivities, if multiple tie to the same 2-hop neighbor nodes, select the one having maximum number of 2-hop neighbors and that meet an optimal QoS metrics as MPR. If more than one node in 1-hop neighbor can cover the same maximum number of nodes in 2-hop neighbor, a 1-hop neighbor having a better QoS metrics in terms of delay, quality, and bandwidth is selected as MPR.

The drawback in the existing three schemes of MPR selection is that the selected of MPR set may not represent the optimum selection. This is because in the selection process, there may be more than one node in 1-hop neighbors that cover the same maximum number of nodes in 2-hop neighbor. If one of the nodes that cover this maximum number is selected, for example, by considering the node's bandwidth only, this is not enough to ensure the optimum selection. The node having a better QoS metrics may be omitted. May be the selected MPR node has high delay and low link quality. Therefore, as we are providing full-fledged QoS routing, the criteria for the selection of MPR nodes should satisfy all possible constraints.

#### 5.4.2 Costs of MPR Selection Algorithms

In order to calculate the forwarding nodes, a certain number of procedures and information are required. These requirements form the cost of the MPR selection algorithm. Four costs of MPR algorithms are described as follows [34]:

**a. Time Complexity:** it is the time required to complete the forwarding nodes calculations. A heuristic that requires much time to run the calculation may be too complex to be deployed. Furthermore, when the network topology changes rapidly, the frequency of a forwarding node calculation also increases, and thus the time consumption of the calculation is huge for a complex heuristic. Hence, an efficient heuristic that consumes less time is essential for the MPR set generation.

**b. Message Complexity:** it is the number of HELLO messages required for the calculation of the MPR set. For any MPR scheme, a number of HELLO messages need to be exchanged between nodes in advance. These HELLO messages contain the necessary information for a heuristic to implement the forwarding node set calculation. Algorithms in different groups or even in the same group may require a different number of HELLO messages. However, frequent information exchange will consume the limited bandwidth in MANETs and also accelerates the energy consumption of mobile nodes. Therefore, the number of HELLO messages exchanged, which is regarded as the message complexity, can significantly affect the performance of an MPR algorithm.

**c. Information Range:** it is the hop level of neighboring nodes information (i.e. two-hops, three-hops, etc.) needed for the calculation of MPRs. Generally, the larger information range an

algorithm requires, the more time and message exchange it will need. For example, an information range up to four hops may not be efficient for an MPR algorithm because messages need a long time to be transmitted to the source node and the information they carry may be outdated by then.

**d. Source Dependant:** a forwarding node needs to know from which node the packet was received in order to determine whether or not to retransmit this packet. If an algorithm is not source dependant, a forwarding node will broadcast all messages that are received for the first time. This requirement increases the complexity of both the message sending and receiving process in an algorithm.

Surveys [34], compare MPR selection algorithms based on the above cost, and their result is summarized in Table 5.3, where  $|N_1|$  represents the maximum number of 1-hop neighbors of a node,  $|N_2|$  represents the maximum number of 2-hop neighbors of a node and M represents the maximum number of MPRs selected by a node.

*Table 5.3: Cost Comparison Result of MPR Selection Algorithms*

<b>Algorithm</b>	<b>Time complexity</b>	<b>Message Complexity</b>	<b>Information Range</b>	<b>Source Dependant</b>
QoS MPR-1	$O(3 N_1 M +  N_2 )$	$O(2 N_1  +  N_2 )$	2 hops	Yes
QoS MPR-2	$O(3 N_1 M +  N_2 )$	$O(2 N_1  +  N_2 )$	2 hops	Yes
QoS MPR-3	$O(2 N_1  N_2 )$	$O(2 N_1  +  N_2 )$	2 hops	Yes
Proposed QoS MPR Selection	$O(2 N_1  N_2 )$	$O(2 N_1  +  N_2 )$	2 hops	Yes

The cost comparisons of the algorithms focus on the cost for the source node to complete the MPR set calculation so that all 2-hop neighbors of the source node can be covered. The result of Table 5.3 depends on the steps of MPR selection algorithms. In our proposed QoS MPR selection, we assume that  $O(N_1)$  time might be needed at most to find out all 1-hop neighbors that solely cover some 2-hop nodes. Then, for each 2-hop node, add to the MPR set a node that can provide the maximum QoS metrics value. This step takes  $O(|N_1|)$  time to run. Since these two steps have to be operated for all 2-hop neighbors, the total time complexity of the algorithm can be  $O(2|N_1||N_2|)$ . As we got from the surveys, QoS MPR-3 has the same time complexity with proposed QoS MPR selection. Therefore, at the worst time scenario, these two schemes

require less time to complete the forwarding node calculation. To calculate the message complexity, a number of messages exchanged between 1-hop and 2-hop neighbors are considered. When we consider multiple constraints in MPR selection, additional QoS information is piggybacked into hello messages and exchanged between neighbors, and thus no extra control messages are generated. Therefore, all algorithms have the same message complexity, a total of  $O(2|N_1| + |N_2|)$  messages required for MPR calculation. As can be seen from Table 5.3, all MPR selection schemes have information range of 2-hops, which means that nodes in these algorithms need knowledge of their 1-hop and 2-hop neighbors, and therefore, each node in the network has to include its 1-hop neighborhood information in its messages. It is also noted that, all algorithms are source dependent; hence each node needs to check from where a packet was sent and whether the sender has selected it as an MPR.

All QoS based MPR selections have the same cost result of message complexity  $O(2|N_1| + |N_2|)$ , information range 2-hop zone, and they are source dependency for forwarding of packets. But, in case of time complexity QoS MPR-3 and Proposed QoS based MPR selection takes lower time,  $O(2|N_1| |N_2|)$ , for calculating MPRs. Hence, selecting QoS MPR-3 and Proposed QoS based MPR selection schemes will provide better performance for completing MPR node calculation.

### 5.4.3 Simulation Results of MPR Selection

In this Section, the performances of the four MPR selection algorithms are evaluated in a typical MANET simulation environment of 600 by 400 meters with 25 nodes having varied node mobility. We run these simulations for 1000 seconds. The efficiency of the algorithms is evaluated in terms of numbers of MPR forms, stability, and overhead. The metrics are described as follows:

**a. Stability:** as we know MANET nodes are mobile; they may not have a stable dedicated place since the nodes, which are selected as MPR, may have a varied location and they may change their state. So, we validated the stability of the algorithms in terms of number of generated MPRs and average life time duration of MPR.

**b. Number of MPR:** average number of MPRs in the network. The more MPRs in the network, the higher the overhead.

**c. Overhead:** Measured as the average number of control packets transmitted at each MPR node during the simulation. Each hop is counted as one separate transmission.

*Table 5.4: MPR Selection Performance Result*

<b>Algorithm</b>	<b>Overhead (# Packets)</b>	<b>Stability (in sec.)</b>	<b>#MPR</b>
QoS MPR-1	67.88	570.87	9
QoS MPR-2	79.28	747.10	11
QoS MPR-3	84.8	891.34	12
Proposed QoS MPR Selection	61.12	928.45	8

Considering varied QoS metrics for selecting MPR nodes, we generated different performance results. The result is based on the capacity of the collected 1-hop neighbors and 2-hop neighbors for a node. In the approaches, the generated values of a number of neighborhood nodes affect the MPR number in the network. The more 1-hop neighbors a node has, the less MPRs it may select, because with a high probability a small subset of its 1-hop neighbor can reach a high number of the 2-hop neighbors (assuming high connectivity of the network). On the other hand, the more 2-hop neighbors a node has, the more MPRs may be needed to cover them all.

All the existing QoS MPR selection approaches were implemented and evaluated on a flat MANET topology. QoS MPR-1, as it considered node connectivity of neighbor nodes, limits the nodes view (small number of 1-hop neighbor can reach all 2-hop neighbors), and selects minimum number of MPRs and overhead of a network. However, QoS MPR-1 does not always find an optimal path, as its MPR selection algorithm may omit the optimal bandwidth link of a node. However, considering overhead and number of generated MPR result as shown in Table 5.4, it is selected and will be evaluated further with our proposed QoS MPR selection for multimedia QoS routing.

Looking at Table 5.4, QoS MPR-2 and 3 attempts to select the best bandwidth path, so in their MPR selection mechanism, they select neighbors with high bandwidth as MPR, resulting in a larger MPR set than QoS MPR-1, thus produce higher overhead than QoS MPR-1.

QoS MPR-3, compared to QoS MPR selection-1 and 2, has a better performance of finding the optimal routes in the network, and is more stable than the two algorithms. Thus, it is selected as one of QoS routing scheme which will be evaluated further with other approaches on varied performance metrics. However, it generates more MPRs compared with other QoS-based MPR algorithms thus increasing the overall retransmissions in the network.

QoS MPR selection- 2 considers only the best bandwidth 1-neighbors as MPRs, as a result, as we see from the Table 5.4, compares with all algorithms, it is not a good solution to select appropriate MPR nodes of a network. Therefore, this algorithm will not be evaluated and used further for QoS routing.

As we see from Table 5.4, our proposed algorithm has better result in terms of packet overhead, stability, and number of MPRs. This is due to the fact that, in this algorithm we considered multiple constraints like delay, quality, bandwidth and connectivity of nodes, and satisfying of optimal required QoS metrics in the selection process. A node having a maximum bandwidth only, is not selected as MPR, instead it checks other constraints as well. Therefore, the proposed selection algorithm outperforms minimum possibility of re-selecting of MPR nodes and the nodes become more stable. In the simulation period, on average, the node which is selected as MPR stays for 928.45 seconds. As we see from the Table 5.4, it minimizes the number of retransmitted control packet of a network into 61.12.

## **5.5 Simulation Experiments and Results**

To test the performance of our proposed QoS routing on a MANET, we have performed a simulation experiment and evaluation using different metrics. To achieve this we followed the following procedure: first, we defined the simulation setup where it encompasses defining the arrangement of MANET nodes in the network as described in Section 5.5.1. Second, we determined the evaluation metrics that help us observe the performance of QoS routing algorithms, and conduct and record simulation results in Section 5.5.2.

### **5.5.1 Simulation setup**

Using OMNET ++ with INET framework, the study has been conducted on a required number of nodes that are changing dynamically. Nodes in the simulation move according to Mass Mobility model. The simulation period takes 1800 seconds and the simulated mobility network area is 600

m x 400 m rectangle. The MAC layer protocol IEEE 802.11 is used in all simulations with a bit rate 2Mbps. The different parameters are shown in Table 5.5.

*Table 5.5: Summary of Simulation Parameters*

Parameters	Value
Number of MANET nodes	30, 40 and 50
Scenario size	600 X400
Application type	Video streaming
Mobility	Mass Mobility model
Simulation time	1800 seconds
Channel type	IEEE 802.11n
Bit rate	2Mbps
Transmission range	100M

### 5.5.2 Performance Evaluation Metrics and Results

In this section, in order to route multimedia data with QoS support, we have evaluated the performance of QoS routing schemes. QoS MPR-1, QoS MPR-3, and Proposed QoS MPR selections schemes are selected considering the result as shown in Table 5.4. The approaches are evaluated in terms of average end to end delay, packet delivery ratio, normalized routing load, and throughput. According to survey [10, 11, 20], the metrics are discussed as follows:

**a. Average End to End Delay (AEED):** This is the average time delay for data packets from the source node to the destination node. This metric is calculated by subtracting “time at which first packet was transmitted by source” from “time at which first data packet arrived to destination”. This includes all possible delays caused by buffering during route discovery latency, and processing at intermediate nodes.

**b. Packet Delivery Ratio (PDR):** This is the total number of delivered data packets divided by total number of data packets transmitted by all nodes. For all our simulations we have kept the same traffic model. So a routing scheme having a higher packet delivery ration results in lower packet loss rate. This evaluation metric will give us an idea of how well the scheme is performing in terms of packet delivery at different network density.

**c. Normalized Routing Load (NRL):** It represents the ratio of the number of control packets propagated by every node in the network to the number of data packets received by the destination nodes. This metric reflects the efficiency of the implemented routing scheme in the network.

**d. Throughput (THP):** It is the total number of delivered data packets divided by the total duration of simulation time. In this case, the throughput of each of the routing schemes in terms of number of messages delivered per one second is evaluated.

Based on the evaluation metrics, the performance between the three QoS based routing schemes are evaluated using OMNET++. Detail simulation parameters of MANET nodes are presented in Appendix B.

*Table 5.6: Performance Evaluation Result*

	Selection Approach	Network Size (#node)	Total Packet Sent (#packet)	Total Packet delivered (#packet)	Performance			
					PDR (%)	AEED (ms)	NRL	THP (byte/s.)
<b>Standard OLSR</b>	QoS MPR-1	30	479	340	71	32.18	1.05	419.35
		40	539	371	68	37.09	2.03	578.98
		50	793	459	58	41.09	2.81	592.10
	QoS MPR-3	30	512	404	79	21.79	1.96	517.67
		40	654	477	73	26.37	2.31	629.76
		50	807	500	62	33.50	3.05	638.47
<b>Clustered based OLSR</b>	Proposed QoS MPR selection	30	534	514	96	12.57	0.57	565.33
		40	626	519	82	18.88	0.98	641.28
		50	843	623	74	28.94	1.92	654.93

After performing exhaustive simulations with varied network sizes for the defined parameters, vector and scalar data are recorded and stored in a spreadsheet file. The data can later be analyzed and transformed into a table as shown in Table 5.6, and illustrated in a graph as follows:

In our simulation, in order to calculate the end to end delay of a packet, we timestamp a packet when the source node starts sending a data packet and also the time when that particular packet reached to the destination node for all packets transmitted for a single simulation experiment.

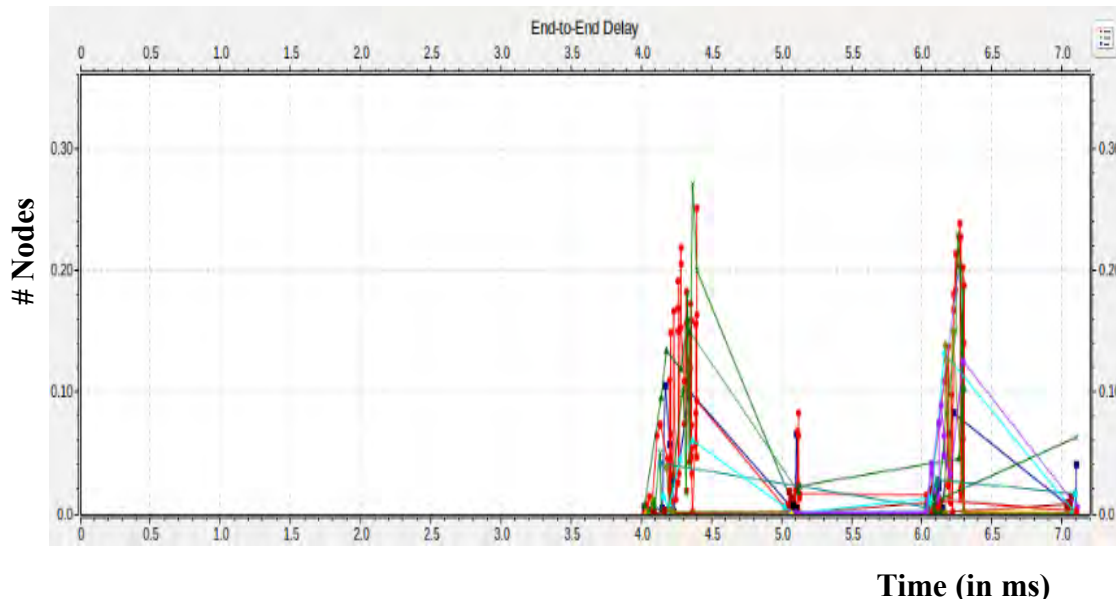


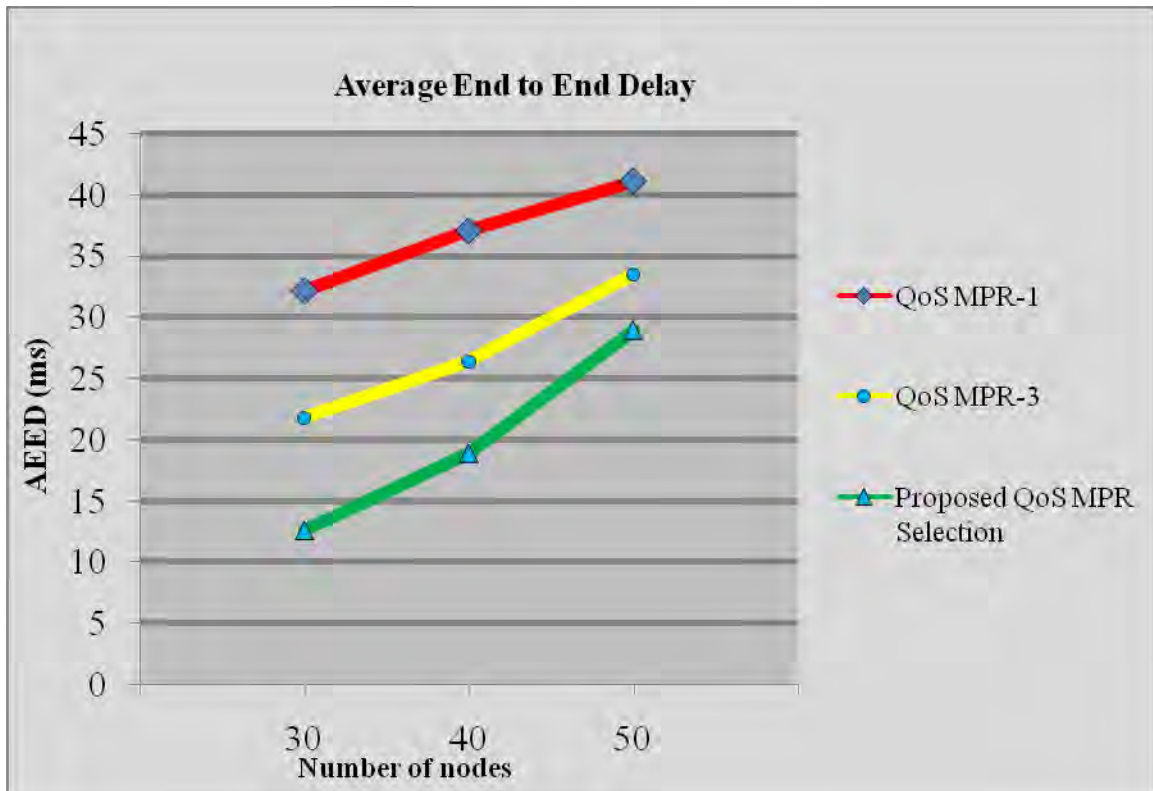
Figure 5.5: EED Result Recorded by all Nodes

	Standard	Standard
1	time	mnet.host[8].clustering.End-to-End Delay
2	4.025114833223	0.00511483
3	4.148599540026	0.00384886
4	4.176027209173	0.104778
5	4.201993152831	0.0572423
6	4.202760524505	0.00532831
7	4.225970133688	0.0285381
8	4.23553572686	0.00126219
9	4.33549072077	0.101217
10	5.102666302839	0.00221305
11	5.105005239212	0.0648472
12	5.113055538802	0.000500045
13	6.081816621077	0.00101758
14	6.096512607037	0.0139341

Figure 5.6: EED Result Recorded by one Node

Figure 5.5 shows a statistical graph that analyses and displays EED results, when the packet is received by the destination during the simulation of a scenario. The statistical graph can be

exported to spreadsheets in CSV format for further analysis as shown in Figure 5.6. Each line of Figure 5.5 represents an end to end result of a single host having a value as shown in Figure 5.6. Thus, by computing the mean value of all hosts we can get the value of AEED as shown in Table 5.6.

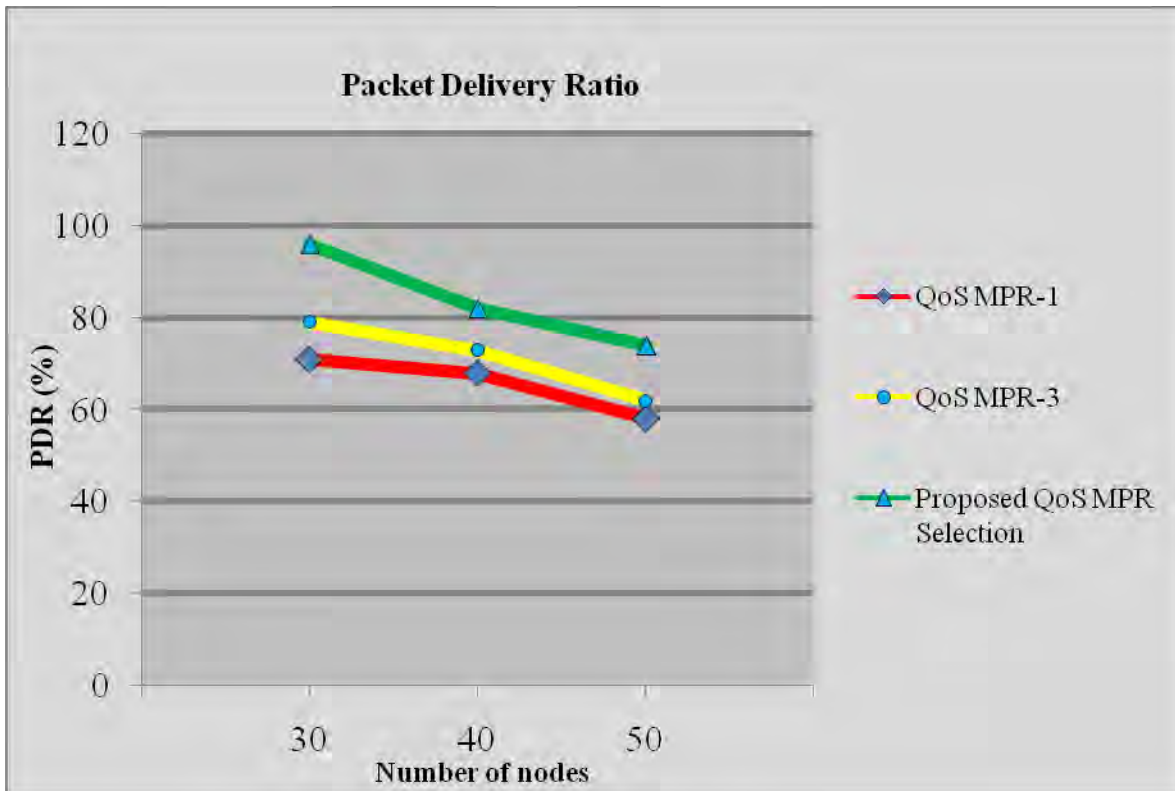


*Figure 5.7: AEED for Routing a Packet on different QoS Routing Schemes*

The graph shown in Figure 5.7 displays the behavior of three QoS schemes of a routing protocol under varying network sizes and topology for average end to end delay. As can be seen from the graph, clustered based with our proposed QoS MPR selection has shown lower end to end delay in all network sizes. This is due to the fact that based on clustering information the network is more manageable, less number of intermediate nodes, easy to maintain optimal route and each node maintains stable routing information and have less congested routes. However, routing on a dense network having 50 nodes has high topology updates so the more frequently sent update messages tend to make the network busy resulting in a high congestion and packet delay. However, cluster based with our proposed QoS selection limits the change of the topology to a specified range without affecting the whole network. This shows that the proposed scheme

provides lower average end to end delay than the other two schemes. The other thing, in the proposed QoS MPR selection, delay was considered as one of a selection criteria.

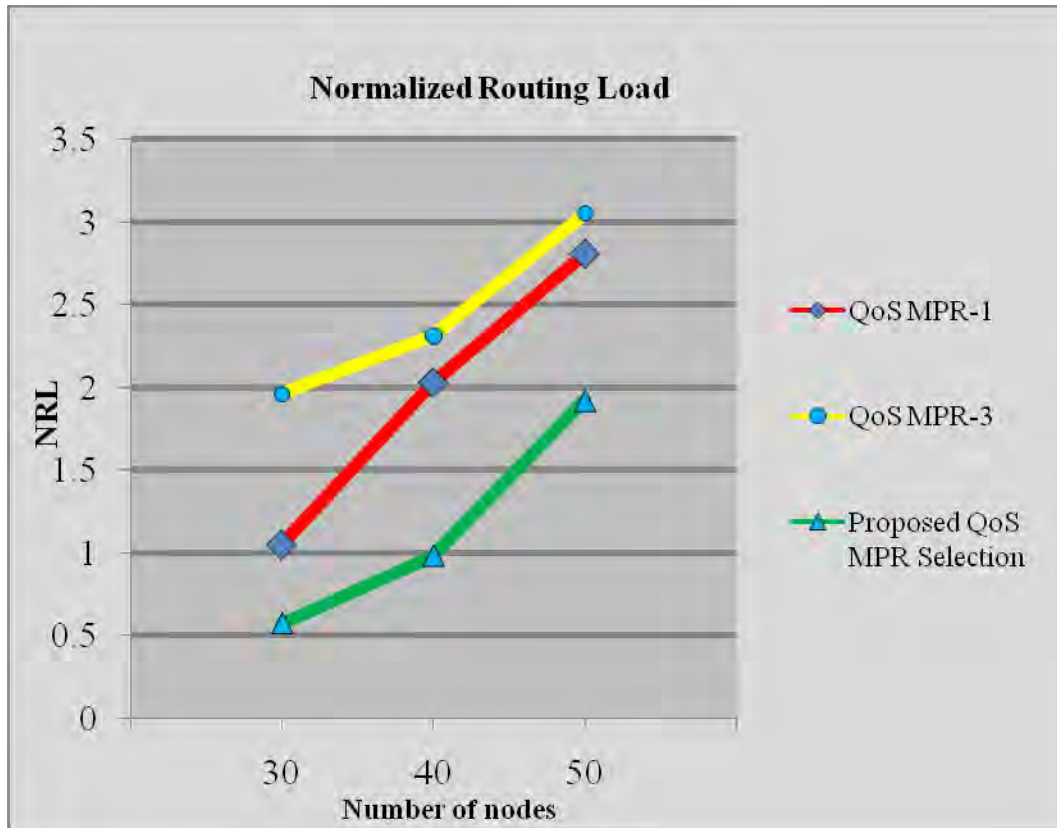
To evaluate the ability of our QoS routing to reliable delivery of packets, we computed and compared the PDR achieved by a testing packet. In Table 5.6, we have shown the number of packets sent and delivered to the destination on different QoS routing schemes.



*Figure 5.8: PDR Result for Routing a Packet on different QoS Routing Schemes*

Packet delivery ratio for QoS routing schemes decreases as the size of the network increases. This is because, at higher network size, link breakage and congestion of packets may occur more frequently and a packet loss fraction increases. As shown Figure 5.8, compared with QoS MPR-1 and 3, our proposed QoS MPR selection has the highest packet delivered ratio because the routes are optimal and has minimal number of unreachable list of next hop nodes for a particular destination node. As we consider the quality of links, the established links between the nodes have a lower probability to break. Thus, there are list of optimal routes in the node routing tables, which results in a higher ratio for correct packet delivery.

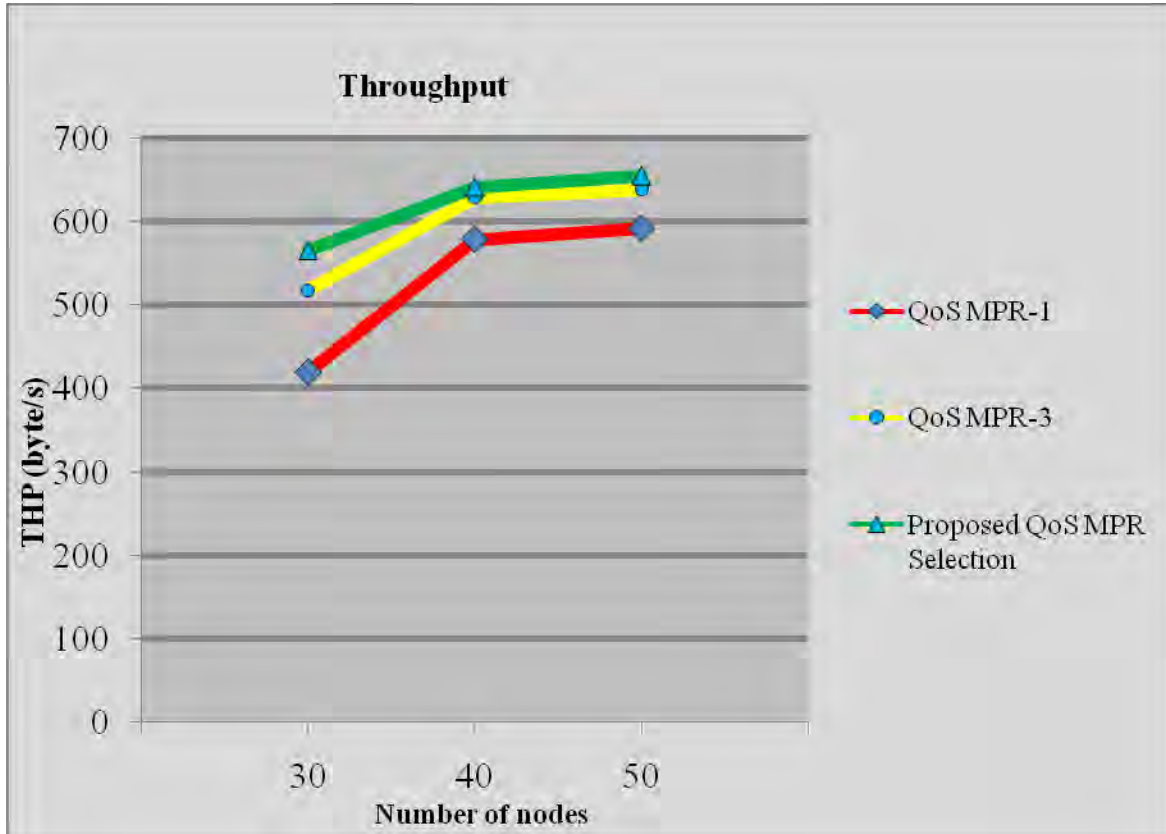
Because of the proactive nature of the routing schemes, MANET nodes usually need to maintain accurate information in their routing table. They attempt to continuously evaluate all of the routes within a network. This means to get appropriate routing information, periodically a number of control messages are broadcasted in the network. When we increase the network density, there is a possibility of retransmission of control messages becoming more crowded, and results in lower delivery of routing packets.



*Figure 5.9: NRL Result for Routing a Packet on different QoS Routing Schemes*

As we observe from the simulation result shown in Figure 5.9, the reason for normalized routing load difference among the three QoS routing algorithms depends on the number of control messages which are retransmitted in the network. QoS MPR-1 and 3 have high flooding rate of multicasting and broadcasting messages. However, applying cluster schemes on the proposed QoS MPR selection minimizes the overhead of a network by limiting the network view of each node. Therefore, the proposed routing scheme results in lower routing overhead than the other two QoS routing schemes.

As we observe from the simulation, the number of bytes which are successfully delivered by all destination nodes within a simulation time increases in the network which is more efficient. This efficiency comes through well maintained routing information.



*Figure 5.10: Throughput Result for Routing a Packet on different QoS Routing Schemes*

The more efficient of a network results the higher throughput, a lower packet loss rate, and the better the delivery ratio. From Figure 5.10, it can be observed that the performance of the proposed QoS routing provided better packet delivery over the simulation time. This is due to the fact that applying clustering scheme on the network helps managing the network, and maintaining routing information better. As a result, when we route a particular packet within a specified simulation period, the source node gets the most correct routing information about the network topology, and it delivered accurately with a lower link breakage and congestion of network. A higher value of average throughput requires low end to end delay, lesser packet loss, lower normalized routing load and higher packet delivery fraction.

## 5.6 Summary

As our objective of providing a better QoS routing in MANETs, QoS based approaches were designed to adaptively provide better management for dynamic changes of network topology. To compare it with the existing works, we conducted a simulation on a MANET environment using OMNET++, and performed evaluation with different parameters. In all simulation parameters the performance of the network decreases with the increase of the number of nodes. This is due to the increase of the number of intermediate mobile nodes resulting in high probability of path breakage and loss of data packet, and increases updating of topology information.

The simulation experiment result shows that our proposed QoS routing provides a better performance for QoS required applications with high throughput and packet delivery ratio, and minimizing delay and routing load. This is due to the fact that in our proposed QoS routing approach, we were considered multiple constraints for MPR selection and route calculation, and nodes were grouped each other based on clustering algorithm. As we see the results, all QoS evaluation metrics have good performance, which makes the proposed QoS routing a candidate and primary choice scheme for deploying especially in a time sensitive application like video streaming, online conferencing, VoIP, etc.,.

## **Chapter Six: Conclusion and Future Work**

### **6.1 Conclusion**

In recent times, with the rise of mobile devices as well as progress in wireless communication, ad hoc networking is gaining importance with the increasing number of wide spread applications. However, QoS routing in an Ad hoc network is difficult because the network topology may change constantly and the available state information for routing is obviously indefinite. To support QoS, the link state information such as bandwidth, routing overhead, delay, packet loss, etc., in the network should be available and manageable. In this work, approaches to improve QoS routing in MANET protocols were discussed. In order to limit the activity of all nodes to a specific range, to decrease the number of communicating intermediate nodes, and to improve routing efficiency and scalability of nodes, we have reviewed and implemented Lin's clustering algorithm. Every mobile node in the network maintains its node ID with respect to its neighbor node connectivity. By comparing this information with the neighbor nodes, a node becomes a member of one of a clustering state cluster head, gateway or ordinary.

Applying clustering schemes in such kinds of networks facilitates the performance of a routing protocol by reducing the routing complexity and minimizing the rate of broadcast and multicast messages. As per our proposed routing protocol, OLSR provides a strategy that discovers the best routing paths that links up two or more nodes in a network. It is a proactive protocol and can result in higher overhead due to continuous route updating of a topology. To cover 2-hop neighbors, designing a new approach for selecting MPR nodes will improve the service of OLSR. Thus, initially, three QoS support MPR selection algorithms namely QoS MPR-1, QoS MPR-2, and QoS MPR-3 with our proposed QoS MPR selection algorithms were evaluated in terms of packet overhead, stability, and number of MPRs. As we are considering multiple constraints and applying of clustering schemes, the result shows that our proposed selection algorithm outperforms minimum possibility of re-selecting of MPR nodes and the nodes become more stable. In the simulation period, on average, the node which is selected as MPR stays for 928.45 seconds. It selects with minimum number of MPR, and it minimizes the number of retransmitted control packets of a network into 61.12.

Furthermore, we have proposed an algorithm for optimal routing computations and forwarding of packets. To obtain the shortest path to every other node more than 2-hops away, each node maintains routing information using information from the 1-hop and 2-hop neighbors and the topology table done by the clustering algorithm. Routing tables include the next node and number of hops to reach every other node in the network. As we are using hop by hop routing method, the source node stores in its routing table the next hop to reach the destination node of a packet. Each node has video server and video client modules in our simulation. However, at a time only one node is selected as server node and the other nodes become client nodes. When a client node wants to have a video packet, based on routing information, it requests and receives a streaming video packet from a server node.

Finally, we have evaluated the proposed QoS routing with the existing ones. Cluster based with proposed QoS MPR selection outperforms in all evaluation criteria on varied network density. It provides a better performance for QoS required application with high throughput and packet delivery ratio, and minimizing delay and routing load. Hence, considering multiple QoS metrics for MPR node selection and maintaining route information, and deploying the routing protocol on clustered topology of a mobile ad hoc network improves the services of MANET nodes.

## **6.2 Future Work**

The proposed QoS routing approach allows a better performance for QoS requiring MANET applications like multimedia data communication. It was promised to resolve the problems of the existing routing protocols by considering multiple constraints and applying on clustered MANET topology. The result shows that QoS support routing is improved in terms of delay, overhead, packet loss, etc.

Even though, we tried our best to realize the proposed approach for QoS routing in MANET using OLSR protocol with the objective of addressing the shortcomings of existing works, we do not believe that the approach is generic enough to incorporate potential issues in MANETs. For instance, despite the importance of the issue, we have not considered the security aspect of MANET networks in our work since it was beyond the scope of this work. Therefore, we recommend that the proposed approaches can be enhanced in such a way that the security of MANET networks is taken into account.

Also in case of high traffic flow of MANET networks, we have not considered load balancing techniques. Thus, we suggest that to address packet congestion due to high flow of packets, load balancing of MANETs should be taken into account and the proposed approaches should be improved.

The other line of improvement is regarding mobility of MANET nodes. MANET nodes are highly movable causing path breaks, continuous topology changes, and resource scarcity like battery, memory, etc. Therefore, designing new routing protocols that could fully address routing problems is another area of improvement to maximize its usability in a real time sensitive application in the future.

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## Appendix A: NED file Code for the Proposed QoS Routing

```
package inet.nodes.inet;

import inet.applications.IPingApp;
import inet.applications.ISCTPApp;
import inet.applications.ITCPApp;
import inet.applications.IUDPApp;
import inet.transport.ISCTP;
import inet.applications.udpapp.UDPBasicApp;
import inet.applications.tcpapp.sampleapp;
import inet.transport.ITCP;
import inet.transport.IUDP;
import inet.applications.udpapp.UDPVideoStreamCli;
import inet.applications.udpapp.UDPVideoStreamSvr;

module StandardHost extends NodeBase
{
  parameters:
    @display("i=device/pc2;bgb=1000,,lightGreen");
    int numTcpApps = default(0);
    int numUdpApps = default(0);
    int numSctpApps = default(0);
    int numPingApps = default(0);
    bool hasTcp = default(numTcpApps>0);
    bool hasUdp = default(numUdpApps>0);
    bool hasSctp = default(numSctpApps>0);
    string udpType = default(firstAvailable("UDP","UDP_None"));
    string sctpType = default(firstAvailable("SCTP","SCTP_None"));
    IPForward = default(true);
    networkLayer.proxyARP = default(false);

  submodules:

  vedioclient: UDPVideoStreamCli {
    parameters:
      @display("p=177,141,row,60");
  }
  vedioserver: UDPVideoStreamSvr {
    parameters:
      @display("p=255,85,row,60");
  }

  tcp: <tcpType> like ITCP if hasTcp {
    parameters:
      @display("p=173,225");
  }
  clustering: UDPBasicApp {
    parameters:
      @display("p=352,77,row,60");
  }

  udp: <udpType> like IUDP if hasUdp {
    parameters:
```

```

        @display("p=313,186;i=block/wheelbarrow");
    }
    sctpApp[numSctpApps]: <> like ISCTPApp {
        parameters:
            @display("p=558,58,row,60");
    }
    sctp: <sctpType> like ISCTP if hasSctp {
        @display("p=439,173");
    }
    pingApp[numPingApps]: <default("PingApp")> like IPingApp {
        parameters:
            @display("p=635,141,row,60");
    }
connections allowunconnected:

tcp.ipOut --> networkLayer.tcpIn if hasTcp;
tcp.ipIn <-- networkLayer.tcpOut if hasTcp;

for i=0..numUdpApps-1 {
    clustering.udpOut --> udp.appln++;
    clustering.udpIn <-- udp.appOut++;
    vedioclient.udpIn <-- udp.appOut++;
    vedioclient.udpOut --> udp.appln++;
    vedioserver.udpIn <-- udp.appOut++;
    vedioserver.udpOut --> udp.appln++;
    vedioclient.clusterin <-- clustering.aplout;
}

udp.ipOut --> networkLayer.udpIn if hasUdp;
udp.ipIn <-- networkLayer.udpOut if hasUdp;

for i=0..numSctpApps-1 {
    sctpApp[i].sctpOut --> sctp.from_appl++;
    sctp.to_appl++ --> sctpApp[i].sctpIn;
}
sctp.to_ip --> networkLayer.sctpIn if hasSctp;
networkLayer.sctpOut --> sctp.from_ip if hasSctp;

for i=0..numPingApps-1 {
    networkLayer.pingOut++ --> pingApp[i].pingIn;
    networkLayer.pingIn++ <-- pingApp[i].pingOut;
}
}

```

## Appendix B: Ad hoc host Simulation Parameters

```
[General]
network = MANET
#cmdenv-output-file = omnetpp.log
#record-eventlog = true
#eventlog-message-detail-pattern = *:(not declaredOn(cMessage) and not declaredOn(cNamedObject)
and not declaredOn(cObject))

sim-time-limit = 1800s

num-rngs = 3
** .numRadios = 1
** .numUdpApps = 1
** .messageLength = 1B
** .sendInterval = 10ms
** .multicastInterface = "wlan0"
** .mobility.rng-0 = 1
** .wlan[*].mac.rng-0 = 2
#debug-on-errors = true

tkenv-plugin-path = ../../etc/plugins

** .constraintAreaMinX = 0m
** .constraintAreaMinY = 0m
** .constraintAreaMinZ = 0m
** .constraintAreaMaxX = 600m
** .constraintAreaMaxY = 400m
** .constraintAreaMaxZ = 0m
** .debug = true
** .coreDebug = false
** .host* .channelNumber = 0

** .udpApp[0].localPort = ""
** .udpApp[0].destPort = ""
** .udpApp[0].messageLength = 512B #
#** .udpApp[0].sendInterval = 0.1s
** .udpApp[0].sendInterval = 0.2s + uniform(-0.001s,0.001s)
** .udpApp[0].sleepDuration = 1s
# channel physical parameters
* .channelControl.carrierFrequency = 2.4GHz
* .channelControl.pMax = 2.0mW
* .channelControl.sat = -110dBm
* .channelControl.alpha = 2
* .channelControl.numChannels = 1

# mobility
** .host* .mobilityType = "MassMobility"
** .host* .mobility.initFromDisplayString = false
** .host* .mobility.changeInterval = truncnormal(2s, 0.5s)
** .host* .mobility.changeAngleBy = normal(0deg, 30deg)
** .host* .mobility.speed = truncnormal(20mps, 8mps)
```

```

**.host*.mobility.updateInterval = 100ms

# ping app (host[0] pinged by others)
**.host[0].numPingApps = 0
**.host[*].numPingApps = 2
**.host[*].pingApp[*].destAddr = "host[0]"
**.pingApp[0].startTime = uniform(1s,5s)
**.pingApp[1].startTime = 5s+uniform(1s,5s)
**.pingApp[*].printPing = true

# ip settings
**.routingFile = ""
**.ip.procDelay = 10us
# **.IPForward = false

# nic settings
**.wlan[*].bitrate = 2Mbps

**.wlan[*].mgmt.frameCapacity = 10

**.wlan[*].mac.address = "auto"
**.wlan[*].mac.maxQueueSize = 14
**.wlan[*].mac.rtsThresholdBytes = 3000B
**.wlan[*].mac.retryLimit = 7
**.wlan[*].mac.cwMinData = 7
**.wlan[*].mac.cwMinBroadcast = 31

**.wlan[*].radio.transmitterPower = 2mW
**.wlan[*].radio.thermalNoise = -110dBm
**.wlan[*].radio.sensitivity = -85dBm
**.wlan[*].radio.pathLossAlpha = 2
**.wlan[*].radio.snrThreshold = 4dB

[Config Ping1]
description = "host1 pinging host0"
*.numHosts = 50

## OLSR
[Config OLSR]
**.routingProtocol="OLSR"
**.Willingness = 3
**.Hello_ival = 2s
**.Tc_ival = 5s
**.Mid_ival = 5s
**.use_mac = 0 #1
**.Link_quality = 2
**.Tc_redundancy = 3

```

## **Declaration**

I, the undersigned, declare that this thesis work is my original work, has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been duly acknowledged.

Name: Kebebew Ababu

Signature: \_\_\_\_\_

Place: Addis Ababa

Date: \_\_\_\_\_

This thesis has been submitted for examination with my approval as a university advisor.

Name: Dr. Mulugeta Libsie

Signature: \_\_\_\_\_

Place: Addis Ababa

Date: \_\_\_\_\_